FOR THE INCREASE AND DIFFVSION OF KNOWLEDGE AMONG MEN

PER ORBEM

SMITHSONIAN INSTITVTION

WASHINGTON 1846

ANNUAL REPORT OF THE BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30

1931

(Publication 3142)

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LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

SUBMITTING

THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE INSTITUTION FOR THE YEAR ENDED JUNE 30, 1931

SMITHSONIAN INSTITUTION,
Washington, February 10, 1932.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1931. I have the honor to be,

Very respectfully, your obedient servant,

C. G. ABBOT, *Secretary.*

40352

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[1] In part governmentally supported.

General Appendix

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SUBJECTS

1. Annual report of the secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1931, with statistics of exchanges, etc.

2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1931.

3. Proceedings of the Board of Regents for the fiscal year ending June 30, 1931.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1931.

THE SMITHSONIAN INSTITUTION

June 30, 1931

Presiding officer ex officio.—HERBERT HOOVER, President of the United States.

Chancellor.—CHARLES EVANS HUGHES, Chief Justice of the United States.

Members of the Institution:

HERBERT HOOVER, President of the United States.
CHARLES CURTIS, Vice President of the United States.
CHARLES EVANS HUGHES, Chief Justice of the United States.
HENRY L. STIMSON, Secretary of State.
ANDREW W. MELLON, Secretary of the Treasury.
PATRICK J. HURLEY, Secretary of War.
WILLIAM D. MITCHELL, Attorney General.
WALTER F. BROWN, Postmaster General.
CHARLES FRANCIS ADAMS, Secretary of the Navy.
RAY LYMAN WILBUR, Secretary of the Interior.
ARTHUR M. HYDE, Secretary of Agriculture.
ROBERT P. LAMONT, Secretary of Commerce.
WILLIAM N. DOAK, Secretary of Labor.

Regents of the Institution:

CHARLES EVANS HUGHES, Chief Justice of the United States, Chancellor.
CHARLES CURTIS, Vice President of the United States.
REED SMOOT, member of the Senate.
JOSEPH T. ROBINSON, Member of the Senate.
CLAUDE A. SWANSON, Member of the Senate.
ALBERT JOHNSON, Member of the House of Representatives.
R. WALTON MOORE, Member of the House of Representatives.
ROBERT LUCE, Member of the House of Representatives.
IRWIN B. LAUGHLIN, citizen of Pennsylvania.
FREDERIC A. DELANO, citizen of Washington, D. C.
JOHN C. MERRIAM, citizen of Washington, D. C.

Executive committee.—FREDERIC A. DELANO, R. WALTON MOORE, JOHN C. MERRIAM.

Secretary.—CHARLES G. ABBOT.

Assistant Secretary.—ALEXANDER WETMORE.

Chief Clerk and administrative assistant to the Secretary.—HARRY W. DORSEY.

Treasurer and disbursing agent.—NICHOLAS W. DORSEY.

Editor.—WEBSTER P. TRUE.

Librarian.—WILLIAM L. CORBIN.

Appointment clerk.—JAMES G. TRAYLOR.

Property clerk.—JAMES H. HILL.

NATIONAL MUSEUM

Assistant Secretary (in charge).—ALEXANDER WETMORE.
Associate director.—JOHN E. GRAF.
Administrative assistant to the Secretary.—WILLIAM DE C. RAVENEL.
Head curators.—WALTER HOUGH, LEONHARD STEJNEGER, RAY S. BASSLER.
Curators.—PAUL BARTSCH, RAY S. BASSLER, THEODORE T. BELOTE, AUSTIN H. CLARK, FREDERICK V. COVILLE, W. F. FOSHAG, HERBERT FRIEDMANN, CHARLES W. GILMORE, WALTER HOUGH, LELAND O. HOWARD, ALEŠ HRDLIČKA, NEIL M. JUDD, HERBERT W. KRIEGER, FREDERICK L. LEWTON, GERRIT S. MILLER, JR., CARL W. MITMAN, CHARLES E. RESSER, WALDO L. SCHMITT, LEONHARD STEJNEGER.
Associate curators.—JOHN M. ALDRICH, CHESTER G. GILBERT, ELLSWORTH P. KILLIP, WILLIAM R. MAXON, CHARLES W. RICHMOND, DAVID WHITE.
Chief of correspondence and documents.—HERBERT S. BRYANT.
Disbursing agent.—NICHOLAS W. DORSEY.
Superintendent of buildings and labor.—JAMES S. GOLDSMITH.
Editor.—PAUL H. OEHSER.
Assistant Librarian.—LEILA G. FORBES.
Photographer.—ARTHUR J. OLMSTED.
Property clerk.—WILLIAM A. KNOWLES.
Engineer.—CLAYTON R. DENMARK.

NATIONAL GALLERY OF ART

Director.—WILLIAM H. HOLMES.

FREER GALLERY OF ART

Curator.—JOHN ELLERTON LODGE.
Associate curator.—CARL WHITING BISHOP.
Assistant curator.—GRACE DUNHAM GUEST.
Associate.—KATHARINE NASH RHOADES.
Assistant.—ARCHIBALD G. WENLEY.
Superintendent.—JOHN BUNDY.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.
Ethnologists.—JOHN P. HARRINGTON, JOHN N. B. HEWITT, TRUMAN MICHELSON, JOHN R. SWANTON, WILLIAM D. STRONG.
Archeologist.—FRANK H. H. ROBERTS, JR.
Associate Anthropologist.—WINSLOW M. WALKER.
Editor.—STANLEY SEARLES.
Librarian.—ELLA LEARY.
Illustrator.—DE LANCEY GILL.

INTERNATIONAL EXCHANGES

Secretary (in charge).—CHARLES G. ABBOT.
Chief clerk.—COATES W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.
Assistant director.—ERNEST P. WALKER.

ASTROPHYSICAL OBSERVATORY

Director.—CHARLES G. ABBOT.
Assistant director.—LOYAL B. ALDRICH.
Research assistant.—FREDERICK E. FOWLE, JR.
Associate research assistant.—WILLIAM H. HOOVER.

DIVISION OF RADIATION AND ORGANISMS

Chief.—FREDERICK S. BRACKETT.
Research associate.—EARL S. JOHNSTON.
Associate research assistant.—E. D. MCALISTER.
Research assistant.—LELAND B. CLARK.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

Assistant in charge.—LEONARD C. GUNNELL.

REPORT

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. Abbot

FOR THE YEAR ENDING JUNE 30, 1931

To the Board of Regents of the Smithsonian Institution:

Gentlemen: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1931. The first 21 pages contain a summary account of the affairs of the Institution. Appendixes 1 to 11 give more detailed reports of the operations of the United States National Museum, the National Gallery of Art, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the United States Regional Bureau of the International Catalogue of Scientific Literature, the Smithsonian library, and of the publications issued under the direction of the Institution.

SMITHSONIAN INSTITUTION

OUTSTANDING EVENTS OF THE YEAR

An appropriation of $10,000 was made by the Congress for preliminary architectural plans of the extensions to the Natural History Building of the United States National Museum authorized by Congress last year. The new reptile house of the Zoological Park was completed and formally opened to the public on February 27, 1931. A reorganization of several exhibition halls of the Arts and Industries Building of the National Museum has added greatly to the attractiveness of the exhibits of costumes, coins and stamps, and machinery. A small souvenir guide to the Institution and its branches has been published privately by the Smithsonian and seems highly appreciated by visitors. For unity of policy, greater efficiency, and simplification of records and accounts, the separate editorial staffs of the Smithsonian, the National Museum, and the Bu-

reau of American Ethnology have been consolidated under one general management and the offices brought closely together. Two exceptionally valuable publications, The Skeletal Remains of Early Man, by A. Hrdlička, and A History of Applied Entomology, by L. O. Howard, were completed. A bequest netting approximately $50,000 has been received from the estate of the late James Arthur. Its income is to be used for promoting knowledge of the sun. A friend of the Institution has announced to it a large intended bequest to promote and reward original investigation. Numerous valuable research and collecting expeditions by the National Museum, the Bureau of American Ethnology, and the Zoological Park have returned highly successful. Accounts of their results will be found below. A gigantic dinosaur, *Diplodocus longus*, 75 feet long, whose skeleton has been in preparation for several years, has been placed on exhibition. Improved methods of solar-radiation research have been perfected and applied in connection with the observing stations at Table Mountain, Calif., and Mount Brukkaros, Southwest Africa. Volume V of the Annals of the Astrophysical Observatory, containing all results of the years 1920 to 1930, inclusive, on the measurement of solar radiation has been sent to press. The numerous variations of the sun since the year 1920 are represented by monthly mean values whose average probable error is less than 0.1 per cent. Long-continuing regular periodicities in solar variation are demonstrated. Highly accurate results on the spectral distribution of phototropism in plants have been obtained by the Division of Radiation and Organisms. By cooperative work with the Fixed Nitrogen Research Laboratory, excellent results on the absorption of pure organic chemicals in the infra-red spectrum have been reached, and an independent method for determining the ozone content of the earth's atmosphere has been worked out and applied at Table Mountain, Calif.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who, in 1826, bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and therefore constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The affairs of the Institution are administered by a Board of Regents whose membership consists of "the Vice President, the Chief Justice, three Members of the Senate, and three Members of the House of Representatives, together with six other persons other than Members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of them of the same State." One of the Regents is elected chancellor by the board. In the past the selection has fallen upon the Vice President or the Chief Justice, and a suitable person is chosen by the Regents as Secretary of the Institution, who is also secretary of the Board of Regents, and the executive officer directly in charge of the Institution's activities.

Changes in the personnel of the board during the year consisted of the loss of two citizen Regents: Robert S. Brookings, of Missouri, through expiration of his term, and Dwight W. Morrow, of New Jersey, through the automatic expiration of his term as a citizen Regent upon his induction into the office of United States Senator from New Jersey.

The roll of the Regents at the close of the fiscal year was as follows: Charles Evans Hughes, Chief Justice of the United States, chancellor; Charles Curtis, Vice President of the United States; members from the Senate, Reed Smoot, Joseph T. Robinson, Claude A. Swanson; members from the House of Representatives, Albert Johnson, R. Walton Moore, Robert Luce; citizen members, Irwin B. Laughlin, Pennsylvania; Frederic A. Delano, Washington, D. C.; and John C. Merriam, Washington, D. C.

FINANCES

The permanent investments of the Institution consist of the following:

Total endowment for general or specific purposes (exclusive of Freer funds)	$1,747,881.52
Itemized as follows:	
Deposited in the Treasury of the United States, as provided by law	1,000,000.00
Deposited in the consolidated fund—	
Miscellaneous securities, etc., either purchased or acquired by gift; cost or value at date acquired	668,069.02
Springer, Frank, fund for researches, etc. (bonds)	30,000.00
Younger, Helen Walcott, fund (real estate notes and stock, held in trust)	49,812.50
Total	1,747,881.52

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The above-mentioned funds of the Institution are described as follows:

Fund	United States Treasury	Consolidated fund	Separate funds	Total
Arthur, James, fund		$52, 595. 02		$52, 595. 02
Bacon, Virginia Purdy, fund		65, 887. 12		65, 887. 12
Baird, Lucy H., fund		2, 176. 54		2, 176. 54
Barstow, Frederic D., fund		1, 000. 28		1, 000. 28
Canfield collection fund		50, 299. 78		50, 299. 78
Casey, Thomas L., fund		9, 503. 63		9, 503. 63
Chamberlain fund		37, 032. 20		37, 032. 20
Hodgkins (specific) fund	$100, 000. 00			100, 000. 00
Hughes, Bruce, fund		17, 963. 17		17, 963. 17
Myer, Catherine W., fund		22, 744. 20		22, 744. 20
Pell, Cornelia Livingston, fund		3, 175. 03		3, 175. 03
Poore, Lucy T. and George W., fund	26, 670. 00	35, 366. 08		62, 036. 08
Reid, Addison T., fund	11, 000. 00	14, 067. 21		25, 067. 21
Roebling fund		158, 706. 78		158, 706. 78
Smithsonian unrestricted funds:				
Avery fund	14, 000. 00	48, 970. 50		62, 970. 50
Endowment fund		84, 415. 46		84, 415. 46
Habel fund	500. 00			500. 00
Hachenberg fund		5, 291. 03		5, 291. 03
Hamilton fund	2, 500. 00	530. 79		3, 030. 79
Henry fund		1, 590. 43		1, 590. 43
Hodgkins general fund	116, 000. 00	39, 439. 14		155, 439. 14
Parent fund	727, 640. 00	1, 605. 31		729, 245. 31
Rhees fund	590. 00	622. 04		1, 212. 04
Sanford fund	1, 100. 00	1, 170. 63		2, 270. 63
Springer fund			$30, 000. 00	30, 000. 00
Walcott, Charles D. and Mary Vaux, fund		12, 915. 80		12, 915. 80
Younger, Helen Walcott, fund			49, 812. 50	49, 812. 50
Zerbee, Frances Brincklé, fund		1, 000. 85		1, 000. 85
Total	1, 000, 000. 00	668, 069. 02	79, 812. 50	1, 747, 881. 52

The Institution gratefully acknowledges gifts from the following donors:

Dr. W. L. Abbott, for archeological investigations in Haiti.

Estate of James Arthur, for investigations and study of the sun.

Frederic D. Barstow, purchase of animals for Zoological Park.

Mrs. Laura Welsh Casey, further contributions to Thomas Lincoln Casey fund for researches in Coleoptera.

Hon. Charles G. Dawes, for further search in Spain for valuable ancient documents.

Mr. Otto T. Mallery, for preparation of handbook on the Indians of the Southwest.

Research Corporation, for further contributions for research in radiation.

John A. Roebling, for further contributions for researches in radiation and studies in world weather records.

Charles C. Woodley, for general endowment fund of the Institution.

Maj. Leigh F. J. Zerbee, for endowment of the Frances Brincklé Zerbee aquaria.

From an anonymous friend for investigations in Old World archeology.

Freer Gallery of Art.—The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$604, 625. 07
Court and grounds maintenance fund	151, 331. 11
Curator fund	609, 329. 43
Residuary legacy	4, 002, 425. 90
Total	5, 367, 711. 51

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to $5,026.75.

Cash balances, receipts, and disbursements during the fiscal year[1]

Cash balance on hand June 30, 1930		$214, 870. 17
Receipts:		
Cash from invested endowments and from miscellaneous sources for general use of the Institution	$74, 306. 66	
Cash for increase of endowments for specific use	81, 559. 89	
Cash gifts for increase of endowments for general use	5. 00	
Cash gifts, etc., for specific use (not to be invested)	90, 064. 79	
Cash received as royalties from sales of Smithsonian Scientific Series	17, 222. 53	
Cash gain from sale, etc., of securities (to be invested)	317. 09	
Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances)	62,528. 93	
Cash capital from sale, call of securities, etc. (to be reinvested)	63, 998. 50	
Total receipts other than Freer endowment		390, 003. 39
Cash receipts from Freer endowment—income from investments	311, 377. 40	
Gain from sale, etc., of securities (to be invested)	110, 334. 34	
Cash capital from sale, call of securities, etc. (to be reinvested)	1, 160, 106. 80	
		1, 581, 818. 54
Total		2, 186, 692. 10
Disbursements:		
From funds for general work of the Institution—		
Buildings, care, repairs, and alterations	3, 246. 94	
Furniture and fixtures	700. 49	
General administration[2]	23, 091. 60	
Library	3, 163. 31	
Publications (comprising preparation, printing, and distribution)	23, 690. 54	
Researches and explorations	21, 960. 16	
International exchanges	4, 982. 01	
		80, 835. 05

[1] This statement does not include Government appropriations under the administrative charge of the Institution.

[2] This includes salaries of the Secretary and certain others.

Disbursements—Continued.		
From funds for specific use other than Freer endowment—		
Investments made from gifts, from gain from sales, etc., of securities and from savings on income	$78,074.41	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances)	185,547.69	
Cash capital from sale, call of securities, etc., reinvested	59,873.34	
		$323,495.44
From Freer endowment—		
Operating expenses of gallery, salaries, purchases of art objects, field expenses, etc	289,883.42	
Investments made from gain from sale, etc., of securities and from income	110,128.62	
Cash capital from sale, call of securities, etc., reinvested	1,158,127.73	
		1,558,139.77
Balance June 30, 1931		224,221.84
Total		2,186,692.10

Recapitulation of receipts, exclusive of Freer funds, during the year ending June 30, 1931

General uses:		
For addition to endowment	$4,663.67	
Reserved as income	86,870.52	
		$91,534.19
Specific uses:		
Gifts accretions to endowment[3]	81,559.89	
Gifts for specific use not to be invested	90,064.79	
Cash income from endowments for addition to endowment	6,026.26	
Cash income from endowments and from other sources for conducting researches, explorations, etc	56,502.67	
Cash capital from sale, call of securities, etc. (to be reinvested)	64,315.59	
		298,469.20
Total receipts, exclusive of Freer funds		390,003.39

[3] Approximately $22,000 of this amount was paid in connection with the settlement of estate.

Statement of endowment funds

	General purposes	Specific purposes other than Freer endowment	Freer endowment
Endowment fund June 30, 1930	$1, 033, 789. 85	$636, 792. 55	$5, 300, 929. 50
Increase from income, gifts, etc	11, 971. 41	65, 009. 27	5, 697. 95
Increase from gain from sales of securities, stock dividends, etc	204. 07	114. 37	61, 084. 06
Endowment June 30, 1931	1, 045, 965. 33	701, 916. 19	5, 367, 711. 51

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1931:

Salaries and expenses		$38, 304
Gellatly art collection		20, 000
International Exchanges		52, 810
American Ethnology		70, 840
International Catalogue of Scientific Literature		8, 145
Astrophysical Observatory		37, 560
National Museum:		
Furniture and fixtures	$33, 740	
Heating and lighting	93, 120	
Preservation of collections	596, 644	
Building repairs	56, 940	
Books	3, 000	
Postage	450	
Plans for additions to Natural History Building	10, 000	
		793, 894
National Gallery of Art		45, 218
National Zoological Park		220, 520
National Zoological Park, building for reptiles		28, 000
Printing and binding		99, 000
Total		1, 414, 791

MATTERS OF GENERAL INTEREST

PRESENTATION OF LANGLEY MEDAL TO MANLY AND BYRD

As mentioned in my last report, the fifth and sixth awards of the Langley Gold Medal for Aerodromics were made late in 1929 to Charles Matthews Manly (posthumously) and to Admiral Richard Evelyn Byrd, respectively. On December 11, 1930, at the annual meeting of the Board of Regents of the Institution, the posthumous presentation of the medal to Mr. Manly was made through the person of his eldest son. In presenting the medal, the chancellor of the board, Hon. Charles Evans Hughes, spoke of the previous awards and then said:

It was awarded posthumously to Charles Matthews Manly at the board's meeting of December 12, 1929. This exceptional action was taken in recognition

of the fact that the outstanding merit of Mr. Manly's invention and construction of the light, radial, gasoline airplane engine has become more and more apparent in the last years.

Mr. Hughes then quoted Mr. Charles L. Lawrance, president of the Wright Aeronautical Corporation, in part, as follows:

When we consider that the most popular type of airplane engine of to-day is almost identical in its general detail and arrangement with the one evolved by Charles Manly in 1902, we are lost in admiration for a man who, with no data at his disposal, no examples of similar art on which to roughly base his design, and no workmen capable of making the more difficult parts of his engine, nevertheless, through the processes of a logical mind, the intelligent application of the science of mathematics, and the use of his surprising mechanical skill, succeeded in constructing an engine developing 52.4 horsepower for a weight of 125 pounds, or a weight of 2.4 pounds per horsepower, which stood up under severe tests, once even going through a full-power, nonstop run of 10 hours.

Mr. Manly accepted the medal on behalf of his father, and concluded with the words, "I am sure that if he were living there is no honor which he would so greatly treasure."

The presentation of the medal to Admiral Byrd was made at the Smithsonian on the morning of March 27, 1931, by Chancellor Hughes. After reviewing the purpose of the founding of the Langley medal, Mr. Hughes said:

Your investigations in connection with the science of aviation have included severe tests of airplanes, their navigating instruments, and the possibilities of using them for geographical exploration. In these enterprises you have made the nonstop west-east passage of the Atlantic, the first nonstop flight to the North Pole, and the first nonstop flight to the South Pole. You have explored and photographed great regions of the globe hitherto unseen by man.

It gives me great pleasure to present to you, Admiral Byrd, the Langley Gold Medal for Aerodromics, in recognition of your outstanding investigations relating to the application of the science of aerodromics to geographical exploration.

Admiral Byrd, in expressing his appreciation of the award, concluded:

All fliers have the deepest respect for the work of Professor Langley. My own feeling of respect is so profound that this rare medal is doubly precious to me in bearing his name.

His work was epochal in the evolution of aviation, and may I remark here that I believe all age-old things in a state of civilization must follow the great law of evolution as do all things in a state of nature. * * * But here is the big point—because space is practically unlimited the evolution of aviation has fewer limits than ground-held things.

SMITHSONIAN SCIENTIFIC SERIES

In 1926 the Institution reached an agreement with a New York publishing firm for the issuance of a series of popular, illustrated volumes dealing with the branches of science covered by the activi-

ties of the Smithsonian and its branches. The Institution receives a definite royalty from the sale of the books which provides greatly needed additional funds for the continuation of its researches. Volumes 1 to 4 were issued in 1929, and volumes 5 to 8 in 1930. The titles are as follows:

1. The Smithsonian Institution, by Webster Prentiss True.
2. The Sun and the Welfare of Man, by Charles Greeley Abbot.
3. Minerals from Earth and Sky. Part I, The Story of Meteorites, by George P. Merrill. Part II, Gems and Gem Minerals, by William F. Foshag.
4. The North American Indians. An account of the American Indians north of Mexico, compiled from the original sources, by Rose A. Palmer.
5. Insects: Their Ways and Means of Living, by R. E. Snodgrass.
6. Wild Animals in and out of the Zoo, by William M. Mann.
7. Man From the Farthest Past, by C. W. Bishop, C. G. Abbot, and A. Hrdlička.
8. Cold-Blooded Vertebrates, by C. W. Gilmore, D. M. Cochran, and S. F. Hildebrand.

Volumes 9, 10, and 11 were in press at the close of the year, and the manuscript of volume 12 was practically completed.

The first edition of the series to be put on the market was a limited de luxe set known as the James Smithson memorial edition; this was quickly sold out. The publishers are now selling two distinct editions known as the patrons' edition and the William Howard Taft memorial edition.

RESEARCHES IN EUROPEAN ARCHIVES

Dr. C. U. Clark continued his research work among the European archives under the grant furnished by Ambassador Charles G. Dawes in 1929. In addition to the important materials listed last year, Doctor Clark has made some very interesting new discoveries of manuscripts relating to the ethnology of many tribes of North and South America. In the library at Evora in Portugal he brought to light a great many documents of unusual interest which had been deposited by Jesuit missionaries of the early colonial period in Brazil. In the British Museum Doctor Clark discovered some important works of Francisco Cardenas relating to the Maya Indians of Yucatan. In addition to the new work in Portugal and England, Doctor Clark continued his researches in the archives of the Indies at Seville and in the Vatican Library and the Propaganda Fide in Rome. Insomuch as the Dawes fund will expire in September, Doctor Clark will bring his work to a conclusion at that time. The results that have been obtained through this research have been exceptionally valuable, and the interesting material brought to light was considerably more than might have been expected. Although the research was undertaken primarily for the purpose of locating material on the Maya Indians of Yucatan, in

the course of the work documents of unusual interest were found which concerned tribes covering most of North and South America and the islands of the West Indies.

COOPERATIVE ETHNOLOGICAL AND ARCHEOLOGICAL INVESTIGATIONS

In 1928 an appropriation of $20,000 was authorized by Congress for cooperative ethnological and archeological investigations in the United States. Proposed investigations were to be approved by the Secretary of the Smithsonian Institution, who allotted from this appropriation a sum equal to that raised for the work by the organization proposing it. Seven projects were approved during the past year and sums were allotted to them as follows:

Allotments from the fund for cooperative ethnological and archeological investigations during the fiscal year ended June 30, 1931

1930

July 3. Laboratory of Anthropology, to conduct archeological investigations of Basket Maker culture in the Guadalupe Mountain area of southeastern New Mexico for the purpose of locating, exploring, and thoroughly examining both disturbed and undisturbed Basket Maker sites and establishing the principal characteristics of this area. A study and recording of pictographs found in this area will also be made, $900.

July 8. University of Utah, to conduct archeological investigations and explorations in the State of Utah and the intensive excavation of one or two sites chosen as a result of the explorations, $800.

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Feb. 18. Laboratory of Anthropology, to continue the reconnaissance and excavation, where desirable, of Basket Maker sites in the Guadalupe Mountains and adjacent sections on the north and west, $213.15 (together with unexpended balance of $386.85 from previous allotment).

Mar. 26. University of Utah, to conduct archeological investigations at Promontory Point, Great Salt Lake, Utah, and to continue the archeological reconnaissance begun in the fall of 1930 in the drainage of the Sevier River in west central Utah, $250.

Mar. 26. Logan Museum, to conduct archeological investigations along the upper Missouri River, excavating earth-lodge villages belonging to the Arikara before 1850, $250.

Apr. 21. The State Historical Society of Colorado, for a general investigation, reconnaissance, and mapping of the so-called Paradox Valley country with intensive work on a single site to be selected as a result of the reconnaissance, $175.

May 28. University of Denver, to complete the archeological survey of eastern Colorado begun during the summer of 1930, $250.

At the beginning of the fiscal year the balance of the fund for cooperative ethnological and archeological investigations was very low, but by combining the unexpended balances on a number of the allotments it was possible to make the above grants.

EXPLORATIONS AND FIELD WORK

Twenty-nine expeditions went out during the year in the interests of the Institution's investigations in geology, biology, anthropology, and astrophysics. Besides numerous localities in the United States, these expeditions visited many other parts of the world, including Africa, Alaska, Canada, China, Haiti, Santo Domingo, the South Sea Islands, Spain, and the West Indies.

Many unique specimens were brought back to the Institution for study, and much-needed information was obtained in the field. The Smithsonian is indebted to its friends and to other scientific institutions for a considerable part of the expense of these expeditions, as its own meager funds for this purpose were exhausted early in the year.

Among the year's expeditions I may mention particularly Dr. Paul Bartsch's third year of explorations for mollusks in the West Indies, this year's work covering the southern Bahamas, the islands off the south coast of Cuba, and the Caymans; further anthropological researches in Alaska by Dr. Aleš Hrdlička and Henry B. Collins, jr., Doctor Hrdlička working along the Kuskokwim River and Mr. Collins on St. Lawrence Island; biological collecting on "Tin Can Island" in the Tonga Archipelago by Lieut. Henry C. Kellers, United States Navy, through the cooperation of the Navy Department and the United States Naval Observatory; the Parish-Smithsonian expedition to Haiti, organized by the late Lee H. Parish with the financial assistance and cooperation of his father, S. W. Parish, for the purpose of making general biological collections on the little-worked islands off the Haitian coast; and the continuation of the collecting explorations of the Rev. David C. Graham near Suifu, China, which resulted in over 62,000 specimens for the National Museum.

Brief accounts of certain of the year's expeditions will be found in the reports of the National Museum and the Bureau of American Ethnology appended hereto. All are described and illustrated in the Institution's yearly pamphlet, Explorations and Field Work of the Smithsonian Institution, 1930, publication No. 3111.

PUBLICATIONS

On March 1, 1931, the editorial work of the Institution and its branches was consolidated in a central office under the direction of the editor of the Institution. The steadily increasing output of the Smithsonian made it desirable to centralize authority to a certain extent in the interests of a more uniform policy and style and to prevent duplication of effort in the keeping of financial and other records. The volume of work passing through the editorial office

will be apparent from the fact that nearly $120,000 is now spent for printing each year; at certain periods of the year as many as 60 separate publications are in press at one time, some of them containing hundreds of manuscript pages, and most of them highly technical papers requiring careful editing and proofreading. It is hoped that the increased efficiency from a business standpoint of the recent reorganization will result in releasing more time of the small editorial staff for straight editorial work, to the end that Smithsonian publications may appear with greater accuracy and promptness.

The Institution's publications constitute its primary means for accomplishing the diffusion of knowledge. They are issued by the Institution proper and by the bureaus under its administrative direction and appear in 13 distinct series, as follows:

Smithsonian Institution:
- Annual report (with general appendix made up of selected articles reviewing the year's advances in science).
- Contributions to Knowledge (suspended).
- Miscellaneous collections.
- Special publications.

National Museum:
- Annual report.
- Bulletin.
- Proceedings.
- Contributions from the National Herbarium.

Bureau of American Ethnology:
- Annual report (with accompanying papers on ethnological subjects).
- Bulletin.

Astrophysical Observatory:
- Annals.

National Gallery of Art:
- Catalogue.

Freer Gallery of Art:
- Publications.

Ninety-eight volumes and pamphlets were published during the year in these various series, and 205,711 copies of Smithsonian publications were distributed. This number included 27,425 volumes and separates of the Smithsonian Miscellaneous Collections, 25,984 volumes and separates of the Smithsonian annual reports, 4,627 Smithsonian special publications, 86,680 publications of the National Museum, and 29,475 publications of the Bureau of American Ethnology. The titles and authors of the year's publications will be found in the report of the editor, Appendix 11.

LIBRARY

The Smithsonian library contains about 800,000 volumes, pamphlets, and charts, pertaining largely to science and technology. It comprises 10 divisional libraries, one of which—the National Museum

library—includes 36 sectional libraries, the small working units maintained in the offices of the curators and other Museum officials. The year's accessions totaled 14,050, including 6,972 volumes and 7,078 pamphlets and charts. Among the many gifts received during the year may be mentioned several thousand volumes and pamphlets from the library of the late Dr. George P. Merrill, presented by Mrs. Merrill and the other heirs; 600 scientific publications from Mrs. Dora W. Boettcher; and 386 volumes and pamphlets from the heirs of the late Dr. O. P. Hay.

Work on the union catalogue progressed satisfactorily. The staff completed the shelf list of the Museum library, catalogued the publications of the Carnegie Institution of Washington and the John Donnell Smith collection, and made progress in reclassifying and recataloguing the library of the Freer Gallery of Art. A number of special activities were carried forward, such as the checking and completing of sets of publications, the transfer to other organizations of certain publications not needed at the Institution, and the exchange of duplicate publications for others needed to complete sets.

GOVERNMENTALLY SUPPORTED BRANCHES

NATIONAL MUSEUM

The appropriations for the maintenance of the Museum totaled $830,394, which included provision for four additional employees, namely, an associate director, a clerk in the library, and two guards. Although these additions are of great help to the efficient operation of the Museum, there are still many offices, particularly in the scientific departments, where the need for more workers is urgent. The second deficiency bill for 1931 carried $10,000 for the preparation of preliminary plans for the two wings to be added to the Natural History Building under an authorization by Congress in the previous year. These plans, in course of preparation by the Allied Architects Incorporated, will provide for two wings similar in arrangement to the present building, that is, with the ground floor and the third floor devoted to offices and laboratories and the two floors between occupied by exhibits. This additional space will relieve the present badly overcrowded condition in the natural history department of the Museum; a similar need for space will still exist, however, in the arts and industries department and the division of history, and it is hoped that buildings for these collections, which are of such great interest to the public, may soon be provided.

The year's additions to the collections exceeded in number those of any previous year in the Museum's history, reaching a total of 1,022,850 individual specimens. Gifts of duplicates to schools totaled 7,384 specimens, and 31,516 specimens were loaned to scientific workers outside of Washington.

The department of anthropology received additional ethnological material from Alaska resulting from the explorations of Dr. Aleš Hrdlička and H. B. Collins, jr., giving the Museum the most complete collection in existence of the ancient ivory culture of the Bering Sea region. About 5,000 specimens illustrating the life of the American Indian were received as a bequest from the late Victor J. Evans, of Washington. Further material representing the native tribes of West Africa was given by C. C. Roberts.

The most important accession in the department of biology was the Barnes collection of Lepidoptera, purchased by a special appropriation of $50,000 to the Department of Agriculture and transferred to the Museum. Additional material has been received as a result of the field activities of Dr. David C. Graham in China and of Dr. Hugh M. Smith in Siam. Dr. H. C. Kellers obtained large collections of material for the Museum from the island of Niuafoou in the Pacific. A large collection of birds, mammals, reptiles, and plants obtained by E. G. Holt on an expedition to the boundary region between Venezuela and Brazil was presented by the National Geographic Society.

Thirty-two species of minerals new to the collection were received by the department of geology, chiefly by purchase through the Roebling fund. Other interesting accessions included a large mass of native silver and calcite estimated to contain 220 pounds of pure silver; a vertebra of an extinct reptile, which has fossilized into opal; and a green tourmaline weighing 17.9 carats, purchased through the Chamberlain fund. Many valuable fossil specimens were added during the year, particularly through the explorations of C. W. Gilmore and Dr. J. W. Gidley.

In the arts and industries department one of the most interesting accessions was the airplane *Bremen*, the first heavier-than-air craft to make the east-west nonstop flight across the North Atlantic. This was deposited by the New York Museum of Science and Industry. Of especial interest also was a model showing a section of the Conowingo hydroelectric generating station, presented by the Philadelphia Electric Co. The division of graphic arts received a miniature book, The Gospel of St. Matthew, printed in 2½-point type, the smallest type ever cast. Among the especially interesting accessions in the division of history were a chair owned by Benjamin Franklin, a chair belonging to President James Madison, and a mahogany screen owned by George Washington.

In search of specimens and information needed in the progress of the scientific investigations carried on by the Museum many expeditions were in the field during the year, financed either by the Smithsonian Institution or by contributions from interested friends. The

results of the researches of the staff were published by the Museum in 7 volumes and 41 separate papers. The distribution of its publications totaled 86,680 copies. The number of visitors during the year was 1,669,140.

NATIONAL GALLERY OF ART

Three exhibitions were held in the gallery during the year: A collection of 78 water colors by William Spencer Bagdatopoulos, a memorial exhibition of water colors by Henry Bacon, and the fortieth annual exhibition of the Society of Washington Artists.

Art works received by the Institution, subject to transfer to the national gallery upon approval of the National Gallery of Art Commission, included several portraits, among them a portrait of Commodore Stephen Decatur by Gilbert Stuart, bequeathed by the late Stephen Decatur Parsons. Among the loans accepted by the gallery were 15 paintings by British and Dutch masters lent by the executors of the estate of the late Henry Cleveland Perkins, and five paintings by old masters lent by Mrs. Marshall Langhorne.

Four paintings were purchased during the year from the Henry Ward Ranger fund by the Council of the National Academy of Design. Under the conditions of Mr. Ranger's will, the National Gallery may claim any of the pictures thus purchased during the 5-year period beginning 10 years after the artist's death and ending 15 years after his death.

The director, Professor Holmes, calls attention to the fact that just 60 years have passed since he first entered the doors of the Smithsonian Institution, where he was almost immediately employed as an artist. It may be added that since that time, except for short periods of connection with other organizations, he has remained with the Smithsonian and has served it with marked success in the fields of geology and anthropology as well as of art. To few men is it given to achieve distinction in three major fields of activity and to continue at the age of 85 in the able direction of such an important enterprise as the National Gallery of Art.

FREER GALLERY OF ART[1]

Additions to the collections by purchase include a Chinese bronze vessel of the fifth century B. C.; two Chinese jade ornaments of the third century B. C.; Nepalese, Persian, and Arabic manuscripts; and Chinese, Indian, Nepalese, and Persian paintings.

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[1] The Government's expense in connection with the Freer Gallery of Art consists mainly in the care of the building and certain other custodial matters. Other expenses are paid from the Freer endowmennt funds.

The year's curatorial work embraced the studying and recording of inscriptions and seals on recently acquired Chinese paintings and of Buddhist inscriptions on stone sculptures and votive bronze images. The cataloguing of the near eastern section of manuscripts and paintings was completed. Translation of the Persian texts has identified more than 60 Persian miniatures taken from various early manuscripts. Translations have also been made of inscriptions on objects submitted by outside persons and by other institutions for expert opinion. A total of 2,312 objects and 107 photographs of objects were sent in for such opinion.

Important changes in exhibition were made during the year. Galleries I and II are now devoted to the display of works of art from the Near East and India; gallery XIV now contains ancient bronzes, silver, and silver gilt; gallery XVIII exhibits scroll paintings; and gallery XIX displays pottery, porcelain, and panel paintings.

The total attendance for the year was 125,789; of these 1,510 came to the office in connection with studies or for other special purposes. Fifty-two groups were given docent service in the galleries and 10 classes were given instruction in the study room.

In spite of existing difficult conditions, the gallery's expedition in China under direction of C. W. Bishop carried out important excavations in southwestern Shansi. The principal aim of the gallery in this work is to help establish an atmosphere of greater mutual regard and confidence between native and foreign scientists.

BUREAU OF AMERICAN ETHNOLOGY

The bureau continued its diversified researches among the Indians in various parts of the United States and at one locality in Canada. The chief of the bureau, M. W. Stirling, visited several sites of archeological interest in Florida and chose for excavation a large sand burial mound on Blue Hill Island in the Ten Thousand Islands group off the west coast. He then investigated several sites on the island of Haiti in company with H. W. Krieger, of the National Museum. Returning to Florida, work was continued in the eastern part of the State, in the course of which two series of large geometric earthworks were discovered on the eastern side of the Everglades.

Dr. John R. Swanton was engaged in field work among various tribes in Louisiana during the first part of the fiscal year, and later devoted considerable time in Washington to the editing of Gatschet's material on the Atakapa language. Dr. Truman Michelson worked among the Kickapoo and Cheyenne of Oklahoma and the Fox of Iowa. John P. Harrington prepared his report on the San Juan

Indians of California, and later in the year returned to that State to continue his studies, this year on the Esselen and Antoniano Indians in the southern part of Monterey County.

Dr. F. H. H. Roberts, jr., concluded his excavations begun the previous year at a site on the Zuñi Reservation, N. Mex., and later in the year began work on the ruins of a large pit-house village near Allantown, Ariz. J. N. B. Hewitt again visited the Grant of the Six Nations of the Iroquois on the Grand River in Ontario, Canada, and briefly the Tuscarora reservation in western New York State, in connection with the Iroquois texts which he is preparing for publication. Winslow M. Walker was added to the bureau staff as associate anthropologist in March, 1931. Toward the end of the year he left Washington to investigate a number of caves near Gilbert, Ark., and on June 30 the work was still in progress. Miss Frances Densmore continued her study of Indian music for the bureau, working particularly with the Chippewa on Lake Superior and the Seminole of Florida.

The bureau issued two annual reports and three bulletins during the year and distributed 20,475 copies of its publications.

INTERNATIONAL EXCHANGES

The exchange service handles for the United States the official exchange with all other countries of parliamentary documents, departmental documents, and miscellaneous scientific and literary publications.

The number of packages of such publications handled during the year was 641,338, a decrease of 53,327 from the previous year; the weight of this material was 642,190 pounds, a decrease of 65,904 pounds.

As usual, aid was given the Library of Congress in procuring needed foreign publications, as well as a number of other establishments here and abroad in obtaining specially desired publications.

NATIONAL ZOOLOGICAL PARK

The year has been marked at the Zoo by an unusually large number of accessions and by the opening of the new reptile house, enabling the park for the first time to exhibit these interesting creatures. The year's accessions totaled 1,266 animals, while 761 were lost through death, exchange, or return of animals on deposit, leaving a total of 2,501 in the collection at the close of the year. The outstanding accession of the year was the bequest of the Victor J. Evans collection of 244 animals, representing 133 species, which composed Mr. Evans's private zoo and which contained a number

of rarities. To illustrate the unusual importance of the year's additions, it may be said that 63 species were shown for the first time in the National Zoological Park.

Visitors to the park totaled 2,171,515, a slight decrease from the previous year's total. The fact that there was not a greater decline in number of visitors, as there was in other similar institutions owing to the present economic depression, was due to the great public interest shown in the new reptile exhibits. Attendance of school groups numbered 649 from 21 States, comprising 34,026 individuals.

The new reptile house was opened on February 27, 1931, with a reception attended by 3,000 people. The building contains special lighting and ventilating systems and all the modern features known for the best exhibition of animals. Since its opening it has become the most popular building in the entire park. The most urgently needed additional building is one for small mammals and the great apes; plans for this building are now being prepared under an appropriation by Congress for the purpose.

ASTROPHYSICAL OBSERVATORY

A large part of the year's work was devoted to the preparation of text, tables, and illustrations for Volume V of the Annals of the Astrophysical Observatory, which will cover the results of observations made at the several stations since August, 1920. The entire manuscript was sent to the printer toward the end of June.

The three stations at Montezuma, Chile, Table Mountain, Calif., and Mount Brukkaros, Southwest Africa, have continued observations of the radiation of the sun on all possible days. The results from the last two stations have not proved as satisfactory as those from Montezuma, and considerable effort has been expended on improving them. During the year new varieties of the short method of determining the solar constant of radiation, applicable to conditions at Table Mountain and Mount Brukkaros, have been worked out, with resulting great improvement in the values from these two stations.

Upon the completion of the reduction of all the solar constant observations from the three field stations interesting results have been derived from their comparison. Whereas the probable error of the monthly mean values since 1920 is less than 0.1 per cent, the extreme range of the solar-constant values is 2.8 per cent. The march of solar variation since 1920 may be expressed very faithfully as the sum of five regular periodicities of 68, 45, 25, 11, and 8 month intervals. The curve of temperatures at Washington, D. C., and Williston, N. Dak., may also be represented by the sum of these same periodicities with the addition of an 18-month period.

These results are so striking as to offer great hope that the relationship between solar variation and the weather may enable the skilled meteorologist to forecast principal changes of weather far in advance.

In the hope of finding a site as satisfactory as Montezuma, Chile, for solar observations, an expedition supported by John A. Roebling and headed by A. F. Moore is now in the field testing various localities in Africa and outlying regions.

DIVISION OF RADIATION AND ORGANISMS

During the second year of the existence of the Division of Radiation and Organisms, under direction of Dr. F. S. Brackett, a number of researches in physics and chemistry in connection with biophysics were begun. The phototropic experiments upon oat coleoptiles initiated during the previous year were continued with refinement of technique by Doctors Johnston and McAlister. The purpose of this investigation was to determine the phototropic response of the oat coleoptile toward light of different colors, or of different spectral regions, by means of light filters, and this year's more elaborate experiments showed results in striking agreement with the rougher results of the previous year.

Preliminary experiments on the carbon dioxide assimilation of wheat plants were conducted by Doctor Johnson and Mr. Hoover, using special all-vitreous growth chambers. Entire plants are used instead of individual leaves as in earlier work, and a typical day's run of the recording apparatus shows the carbon dioxide assimilated for different light intensities. Equipment is being developed for more elaborate experiments using approximately monochromatic light.

Through the cooperation of the Department of Agriculture, Doctor Meier has carried out preliminary experiments on the growth of algæ under controlled illumination and temperature conditions, a part of her work as National Research Council Fellow in the division. By the use of a large quartz spectrograph, the modifications in growth rate or resulting death point may be observed comparatively for different wave lengths of light.

With the further cooperation of the Department of Agriculture, in connection with the crop physiology and breeding investigations of Doctor Swingle, of the Bureau of Plant Industry, Doctor Meier and members of the division have carried on researches on the effects of controlled radiation, humidity, and temperature on certain tropical and xerophytic plants. It was found possible to maintain conditions that yielded for date palms ten times greater growth rate

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than that of control plants in the greenhouse. Other interesting results were also obtained, which, if applicable to palms, as seems likely, would be of considerable practical importance.

In the field of pure physics and physical chemistry, the intensity distribution in the mercury spectrum has been determined directly, and in cooperation with the Fixed Nitrogen Research Laboratory the spectra of HCl, HCN, and the halogen substitution products of benzene have been investigated in the region between the visible and 2μ. This work has been done by Doctors McAlister and Wulf and Mr. Liddel.

Several additional rooms have been prepared and equipped for the use of the division. The research field of the division is so wide and interesting both to pure science and agriculture that a considerable expansion of its resources and personnel is greatly to be desired.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

In compliance with the resolution passed at the last international convention held in Brussels in July, 1922, the United States bureau of the catalogue has been kept in existence pending resumption of publication, and the compiling of necessary records of current American scientific publications has been continued so that they may be indexed when publication is resumed.

Every effort is being made by the United States bureau, through the chairman of the executive committee of the catalogue, to hasten the necessary reorganization, but the financial depression and other unfavorable conditions have so far prevented the development of a definite plan. Besides the necessary cooperation of the regional bureaus, all that is needed to put the enterprise on its feet is a capital fund of $75,000, to refinance the central editing and publishing bureau.

NECROLOGY

FRANK WIGGLESWORTH CLARKE

Frank Wigglesworth Clarke, honorary curator in the Division of Mineralogy, United States National Museum, since 1883, died at his home in Washington on May 23, 1931, in his eighty-fifth year. Doctor Clarke was chief chemist at the United States Geological Survey from 1883 to 1925, when he retired from active service.

The mineral collection in the National Museum had been recognized as a distinct entity for but a short time prior to Doctor Clarke's appointment as honorary curator. He laid the foundation for these now justly celebrated mineral and gem collections. In addition to

his duties at the survey, he devoted much time and effort to the upbuilding and care of these collections, the early reports of the division testifying to his personal activities. His official retirement from the Government service did not affect his interest, which never flagged. He visited the department frequently, giving freely of the store of knowledge acquired by his long years of service.

Doctor Clarke was also greatly interested in the collection of meteorites, was instrumental in adding to it a number of specimens, and prepared a catalogue which was published as a part of the Smithsonian Report for 1886.

Doctor Clarke was a graduate of Harvard, had many honorary degrees, and was affiliated with several of the prominent scientific societies. He was the author of numerous papers, his Data of Geochemistry being a standard reference work.

Respectfully submitted.

C. G. Abbot, *Secretary.*

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

Sir: I have the honor to submit the following report on the condition and operations of the United States National Museum for the fiscal year ended June 30, 1931:

The total appropriations for the maintenance of the National Museum for this period amounted to $830,394, an increase of $67,880 over the appropriations for the year 1930. Of this amount $12,909, together with a small additional sum secured by readjustment in our salary rolls, provided salaries for four additional employees, namely, an executive officer to be associate director of the United States National Museum, a clerk in the library, and two guards. The new positions provided mark a further advance in the building up of our staff, far too few in number at present for the needs of the Museum.

The second deficiency act for the fiscal year 1931 included $3,596 to cover increases in salaries occasioned by the Brookhart bill, which made adjustment in annual pay in certain minor grades. Congress further provided $11,875 for salary step-ups in connection with efficiency ratings, and $2,420 was received to cover reallocations made by the Personnel Classification Board.

The sum of $1,000 was added for the purchase of additional books for the Museum library, making $3,000 available annually for that purpose. There was further allotted an increase of $1,000 for printing and binding for the National Museum.

As noted in the report for last year, the second deficiency act for the fiscal year 1930 provided $3,500 toward the remodeling of the women's comfort room in the Arts and Industries Building, the expenditure of which came within the operations of the present fiscal year. Other additions under the heading of building repairs included $25,000 for the construction of overhead galleries for the study collection of mammals and $7,000 for fire-protective measures in the aircraft building.

In the appropriation for heating and lighting there was provided an additional $2,000 for the purchase of an electrically driven fire pump for fire protection in the Natural History Building.

The second deficiency bill for 1931 carried provision for $1,620 for an additional clerk and $10,000 for the preparation of preliminary plans for additions to the Natural History Building. These expendi-

tures will figure in the allotment of funds for 1932 and will be considered in the annual report for that year.

Requirements for additional funds for the National Museum follow lines indicated in previous annual reports. The question of further personnel continues to be one of paramount importance, as pressure for additional workers in the scientific, clerical, and custodial forces is constant and continued. Additions made to the staff in recent years have filled in at vital points, but many further positions remain to be provided before our organization can function with maximum efficiency. There are several large collections for which the Museum now has no curators. In some divisions assistants in professional grades are needed as understudies for older men who should be in a position to train successors in their particular fields. Clerical assistance is at a minimum everywhere and in several divisions no service of this kind is at present available. Further subprofessional workers also are needed and the work of the custodial services in our woodworking shops is behind. Temporary clerical and other assistance is provided as funds permit, but this is unsatisfactory, as there is much lost motion in giving necessary training to assistants who under civil service rules remain at most only six months. The gradual increase in staff that has come in recent years has been of great assistance, but additional employees in numerous places are still urgently needed.

Additions to funds allotted for the purchase of books have been useful, but the appropriation available for this purpose should be increased to at least $5,000 a year. Scientific books appear in steadily increasing numbers and at a cost considerably in advance of that of a few years ago, so that the money available for books is below our actual needs. Stimulus to the scientific work in the National Museum in the past few years is beginning to show in steadily increasing amounts of manuscript for publication as the result of researches on the part of the staff. There should be an increase in the funds for printing and binding to allow this material to be published promptly, in order that it may be made available for use by the many persons interested.

As in previous years our existing appropriations are taken up so largely with necessary routine expenditures that there is little money available that may be used in exploration and field work in connection with the National Museum. Many friends and correspondents now make large additions to our collections annually, and the Smithsonian Institution, from its private income, provides funds that are used in an exploration program of considerable importance. The Museum, however, should have in its appropriation adequate funds that would enable it to develop various field researches along logical and continuing lines.

ADDITIONS TO THE NATURAL HISTORY BUILDING

In the report for last year there was a discussion of the Smoot-Elliott bill authorizing the extension of the Natural History Building by adding wings at the east and west ends at a cost of $6,500,000, which was approved by the President on June 19, 1930. As mentioned above, the second deficiency bill for 1931 carried $10,000 for the preparation of preliminary plans for these additions. The Allied Architects Incorporated, of Washington, D. C., have been selected by the executive committee of the Smithsonian Institution to prepare preliminary plans which will be ready for consideration at the time this report is published. Briefly it is planned to add to the present building so that it will extend through the available space from Ninth Street to Twelfth Street, the additional construction to duplicate in general arrangement the present building, with the ground floor and third floor devoted to offices and laboratories and the two intermediate floors given over to exhibits. In so far as modern advances in museum design are found applicable to our needs, they will be incorporated in the plans, and various facilities not at present available will be arranged. It is desired to so schedule the appropriations covering this important matter that funds for the commencement of this work will be provided in the bill for the coming fiscal year. Delay will be highly embarrassing, since our collections in natural history have increased to a point where exhibition and laboratory space is now badly crowded, and under present conditions we must at times make refusal of valuable material that should be in the national collections. In recent years various expedients to provide more space have been adopted, until now we have reached our limit of resources without additional construction. It will be observed in further paragraphs of this report that additions to the exhibition and study collections contained in the Natural History Building in the present fiscal year have reached the vast number of nearly 1,000,000 specimens.

If the building program indicated can be carried out at this time there will be provided adequate quarters for the natural history collections. It must not be overlooked, however, that consideration must soon be given to further construction to house our highly valuable materials in arts and industries and in history.

COLLECTIONS

Additions to the collections of the National Museum during the fiscal year reached the total of 1,022,850 individual specimens, the major part of these coming, as in previous years, to the department of biology. The additions are far in excess of those of any previous

year in the history of the Museum and include individual specimens and collections of high value and great importance. Materials of various kinds received for examination and report during the year amounted to 1,297 lots, including many thousands of separate specimens. Gifts of duplicate materials to schools and other educational organizations included 7,384 specimens, while exchanges of duplicate materials with other institutions and individuals amounted to 33,471 specimens, for which there was received in return material needed for our collections. Loans to scientific workers outside of Washington amounted to 31,516 specimens.

Following is a digest of the more important accessions for the year in the various departments and divisions of the Museum.

Anthropology.—Alaska again has yielded most important accessions to the department of anthropology, the material coming through explorations financed by the Smithsonian Institution. Doctor Hrdlička this year visited the Kuskokwim Valley, the Alaska Peninsula, and adjacent islands, obtaining valuable materials from a region that so far has not been represented in our collections. Work was continued on St. Lawrence Island by Henry B. Collins, jr., who secured additional collections of value in connection with his previous materials from this area. Through our continuing program of exploration the Museum now possesses the most complete and valuable collection in existence of the ancient ivory culture of the Bering Sea region.

Of equal importance in this department has been the bequest of the American Indian collection of the late Victor J. Evans, of Washington. This collection, deposited by the executors of the Evans estate, Mrs. Victor J. Evans and Arthur L. Evans, numbers approximately 5,000 specimens, comprising costumes, weapons of war and the chase, pottery, basketry, domestic implements, oil paintings, and other valuable materials illustrative of the life of the American Indian, many of the objects being now impossible of duplication.

A further collection from west Africa was received as a gift from C. C. Roberts, this material representing the native tribes of Ashanti, Benin, and the Gold and Ivory Coasts. The Carnegie Institution of Washington presented a miniature plaster model of the stucco-covered Pyramid E–VII *sub* at Uaxactun in Guatemala, the oldest known example of Mayan architecture. Under the Bruce Hughes fund of the Smithsonian Institution there were obtained various antiquities from Mesopotamia and Persia for exhibition. As a gift from His Majesty George V of England there has come a chenille Axminster carpet made in 1851.

Textiles, and bone, wood, and stone implements from caves in northeastern Arizona occupied by prehistoric Basket Maker and

Pueblo peoples were presented by Charles L. Bernheimer, of New York City. The Archeological Society of Washington deposited a collection of flint and bone implements from caves near Sergeac, Dordogne, France, collected in 1930 during work of the American School of Prehistoric Research. A series of stone artifacts recovered at Monasukapanough, a prehistoric Indian village in Albemarle County, Va., was presented by D. I. Bushnell, jr.

Biology.—The most important accession in the department of biology, and one of the most important from a scientific standpoint that has come to the Museum in recent years, was the Barnes collection of Lepidoptera, purchased by a special appropriation of $50,000 to the Department of Agriculture and transferred by that department to the National Museum. This collection, consisting principally of moths and butterflies from North America, was assembled by Dr. William Barnes, of Decatur, Ill., during a lifetime of endeavor at an expense of several hundred thousand dollars, and is rich in material of value to the specialist.

Dr. Paul Bartsch, curator of mollusks, traveling under the Walter Rathbone Bacon scholarship of the Smithsonian Institution, obtained extensive collections of mollusks from the West Indies. Additional important specimens in several groups have come from the field activities of Dr. David C. Graham in China and of Dr. Hugh M. Smith in Siam. Large and interesting series of specimens of various kinds were obtained by Dr. H. C. Kellers, United States Navy, while a surgeon on the United States Naval Observatory eclipse expedition to the island of Niuafoou in the Pacific, being the first material to be received by the Museum from that area. The National Geographic Society presented a large collection of birds, mammals, reptiles, and plants obtained by E. G. Holt, as leader of an expedition to the boundary region between Venezuela and Brazil. Much of this collection represents species not found hitherto in the national collections.

Doctor Wetmore, assisted by F. C. Lincoln, of the Biological Survey, obtained interesting collections, chiefly of birds and reptiles, in Haiti and the Dominican Republic. A collection of 3,800 eggs and 12 nests of North American birds was presented by Gov. C. D. Buck, of Delaware. A further collection of birds was obtained by Doctor Wetmore in Spain during field work in the summer of 1930. The division of birds received 16 genera new to its collections, as well as 330 species and subspecies not previously represented, a notable addition to these large collections. Two eggs of the California condor, a species near extinction in the wild state, were received from the National Zoological Park.

A large sailfish caught by Hon. William R. Wood near the island of Sonora, Pearl Island group, Panama, was presented by Mr. Wood

to the Museum and has been mounted and placed on exhibition. It is of maximum size and is far larger than any other in our collections. The Bureau of Fisheries, United States Department of Commerce, transferred a large collection of fishes, principally from Chesapeake Bay and its tributaries.

Type specimens of annelids, sponges, sipunculid worms, and crustacea were presented to the division of marine invertebrates, while 114 types of helminths from Prof. Edward Linton, and the entire collection of Dr. W. G. MacCallum, of Johns Hopkins Hospital, with various other type specimens from collaborators, were added to the section of helminths.

Large collections of grasses from Japan, Madagascar, and elsewhere were transferred by the Department of Agriculture. A large series of specimens of cultivated plants came from the Brooklyn Botanic Garden.

Geology.—Thirty-two mineral species new to the collections were obtained during the year, mainly through purchase under the Roebling fund. There were obtained also under this fund a large mass of native silver and calcite estimated to contain 220 pounds of pure silver, and a section of a vein of similar material carrying 190 pounds of silver from the Keely mine in the cobalt district of Ontario, a large cut black diamond weighing 8.97 carats for the exhibition series, and the fossilized vertebra of an extinct reptile of large size that has been changed in fossilization to a fine quality of precious opal, a most unusual specimen. There was included also a flawless crystal of scapolite, said to be the largest crystal of this mineral yet found, two bowlders of precious jade, and a tourmaline weighing 40½ carats. The Chamberlain fund contributed to the Isaac Lea collection three Mexican opals of unusual color, a green tourmaline weighing 17.9 carats, five rubies from Siam, carved articles of jade, coral, rose quartz, and carnelian, and other interesting and valuable articles.

Specimens of nine meteorites, added to the collection through exchange or purchase, include one complete iron weighing 23 pounds from near Santa Fe, N. Mex., and other valuable examples. A complete set of the potash minerals of the Carlsbad (N. Mex.) deposits was secured with the assistance of Dr. W. T. Schaller through the courtesy of the United States Potash Co. Silver, nickel, and cobalt minerals and ores from various localities in Ontario were collected during field work by the assistant curator of mineralogy. A set of platinum ores from South Africa was obtained through the cooperation of the Geological Survey of the Union of South Africa.

Dr. A. F. Foerste contributed a series of 1,000 invertebrate fossils from the Silurian deposits of the Ohio Valley. Type material in Foraminifera was presented by Dr. J. A. Cushman, Mr. John W.

Skinner, Mrs. F. B. Plummer, and Dr. T. Wayland Vaughan. Many valuable specimens, particularly of fossil mammals, were obtained from collections by C. W. Gilmore in the Eocene deposits of Wyoming, among them being several nearly complete skeletons that will eventually be mounted and placed on exhibition. There may be mentioned especially a nearly complete skeleton of *Hyrachyus*, a rhinoceroslike animal about the size of a tapir, a nearly complete skeleton of *Orohippus*, a small primitive horse, and two more or less complete crocodile skeletons; 38 turtles were obtained belonging to eight genera. Additional fossil horse material resulted from field explorations near Hagerman, Idaho, under Dr. J. W. Gidley.

The collection of fossilized tracks of animals was augmented by an unusually distinct dinosaur footprint from the Triassic of Virginia, presented by F. C. Littleton, of Aldie, Va. Fossil bird bones, types of new species described by Doctor Wetmore, were presented by Dr. E. L. Troxell, of Trinity College, Hartford, Conn. To the exhibitions in the section of paleobotany there came a fine example of a fossilized tree from near Natchitoches, La., presented by George Williamson through the interest of Prof. E. W. Berry.

Arts and industries.—An important accession in the aircraft section was a series of objects illustrating the first use of aircraft for military purposes in the United States, relating to captive balloons used during the Civil War, the collection having come from Prof. Thaddeus S. C. Lowe, organizer of the first military balloon section of the Federal Army. The airplane *Bremen*, the first heavier-than-air craft to make a nonstop flight westward across the north Atlantic, was deposited by the New York Museum of Science and Industry. For the section of land transportation there was secured a coachee, or light family carriage, made in Philadelphia about 1783 that there is reason to believe was owned at one time by General Washington at Mount Vernon. An original Concord stage coach was deposited by Will Rogers and Fred Stone. The Philadelphia Electric Co., through its president, William H. Taylor, presented a model of a section of the Conowingo hydroelectric generating station on the Susquehanna River near Conowingo, Md. Another valuable accession was an original horizontal stationary steam engine built in 1864 in the shops of the United States Military Railroad Department at Alexandria, Va., presented to the Museum by the Southern Railway system. This engine was in operation for 58 years.

The Pepperell Manufacturing Co. presented a model exhibit covering the growth and manufacture of cotton. A number of interesting examples of hand-woven textiles from several individuals included a linen damask tablecloth woven in Vermont about 1780, the design being an illustration of Independence Hall, Philadelphia. This was

presented by Mrs. Jennie Bancroft Alband. Dr. J. T. Lloyd presented a hand prescription balance used many years ago by pharmacists.

In the section of wood technology there were added important collections of woods from Jamaica collected by Gerrit S. Miller, jr., a set of woods from various localities obtained from the Field Museum of Natural History in exchange, and a series of 132 kinds of native woods presented by the Philippine Bureau of Forestry through A. F. Fischer.

For the division of graphic arts there was obtained a miniature book, The Gospel of St. Matthew, printed from 2½-point type, the smallest type that has ever been cast. The printed surface of the page measures 1⅝ by 1⅛ inches and has approximately 540 words to a page.

The trustees of the Stephen H. Tyng Foundation of England have made the section of photography in the Smithsonian Institution the depository for duplicate pictorial prints procured by the foundation. The first installment of photographs from this source came during the year and will be followed by others. The works chosen are selected by the trustees of the foundation as representative works of outstanding pictorial merit produced by the photographers of any nation.

History.—In the antiquarian section a watch and a sword carried during the French and Indian War by Capt. Jeremiah Marston, of the British Army, were presented by Charles F. Clark. There came also a chair owned by Benjamin Franklin, a chair of President James Madison, a mahogany screen belonging to General Washington, and a cane made from a piece of one of the timbers of the U. S. S. *Constitution* by bequest from James C. McGuire.

The aluminum transit used by Admiral Peary during his north polar expedition in 1898 was received as a gift from Mrs. William Porter Allen. A uniform worn during the Spanish-American war by Maj. Gen. Leonard Wood was added to the collections as a gift by Mrs. Leonard Wood. An exceptionally interesting series of military uniforms and equipment was presented by the Rumanian Government through Dr. Andrei Popovici, secretary of the Rumanian Legation. A similar series of Turkish military arms and uniforms came as a gift from the Turkish Government through the Turkish ambassador, Ahmet Muhtar.

For the numismatic collection there were obtained examples of current coins from the Governments of Estonia, Italy, Poland, and the Cameroons. A set of coins from Palestine was presented by P. Knabenshue, American consul general at Jerusalem. Numerous other coins from a large number of countries were transferred by

the Department of State. The United States Treasury Department transferred to the national collections bronze copies of the gold medal awarded by Congress to Col. Charles A. Lindbergh in recognition of his services to the science of aeronautics and of the gold medal awarded by the Congress to Lincoln Ellsworth for his transpolar flight in the dirigible *Norge* in May, 1926. The philatelic collections received 7,855 specimens during the year, the majority having come by transfer from the Post Office Department.

CHANGES IN EXHIBITIONS

In the paleontological series of the Museum exhibition the most important addition has been the installation of the large dinosaur *Diplodocus longus*, collected at the Dinosaur National Monument, Utah. This specimen as mounted in our halls measures more than 70 feet in length and stands 12 feet 5 inches high, with the head and neck rising to a still greater height. The base has been so arranged that at the shoulders and at the hips visitors may walk through beneath the skeleton. This specimen, found embedded in a very hard and difficult rock, has required nearly six years for preparation.

An important change in the historical series has been the transfer of the costumes collection to a larger hall, where the cases containing the series of dresses of wives of the Presidents are now installed in a double row facing one another. This collection is one of the most popular in the Museum and shows to excellent advantage in the large space now available for it.

The numismatic collections have been transferred to the smaller room formerly occupied by the costumes, where the light is much better, allowing the coin and medal series to be viewed more readily, especially on days when artificial light is necessary. The philatelic collection also has been moved to a location where it is much more easily available.

EXPLORATIONS AND FIELD WORK

Field investigations carried on as usual throughout the year have been concerned with a wide variety of interests, and though mainly in the biological field, have included those researches concerned with man and with fossil animals of various kinds, as well as with various groups in botany and zoology. The work has been financed principally through grants from the general income of the Smithsonian Institution, assisted by contributions from interested individuals, while certain projects were financed from special funds of the Institution. Limited assistance has been given from the annual governmental appropriations of the National Museum, but aid from this source has been relatively small and has concerned only a few of the

various projects. Additional money that may be used for researches in the field is one of the principal needs of our organization.

A brief account of field work for the present year follows: During the months of July, August, and September, the assistant curator of ethnology, Henry B. Collins, jr., assisted by J. A. Ford, was engaged in field work on St. Lawrence Island in Bering Sea, in continuation of work begun earlier in the season. In 1928 and 1929 Mr. Collins's excavations on Punuk and St. Lawrence Islands revealed the existence of a prehistoric phase of Eskimo culture ancestral to the modern type of that region and derived apparently from a still earlier phase, known to students as the old Bering Sea culture. Stratigraphic excavations were made this year at Gambell and a long succession of cultural changes was revealed in detail as one village midden after another was trenched. Through this an excellent chronology was established on the basis of stratigraphy, the evidence of the old beach lines, and the demonstrable succession of art styles on implements, principally harpoon heads of walrus ivory. Incidental to this work Mr. Collins took occasion to secure an excellent collection of birds from this island, the bird life of which has been comparatively little known. The active interest of the Revenue Cutter Service in this work continued and was of invaluable assistance, particularly the transportation furnished on the cutter *Northland* to areas otherwise inaccessible. Cooperation from this source has been highly appreciated.

The curator of ethnology, Herbert W. Krieger, engaged in a reconnaissance of an archeological nature in the Republic of Haiti, this work being carried on from January to May, 1931, when the approach of the rainy season brought it to a close. The present population of Haiti has no history or tradition regarding the early Indian occupants of the island, and is therefore of no assistance in locating former Arawak or Ciboney village sites and kitchen middens, so that one has to rely on Spanish and French narratives for the ethnological and historical introduction useful in this work. The reconnaissance was highly successful in determining the distribution of former Arawak and Ciboney village sites, and it was found that scattered groups of each type occupied at different times much of the habitable portions of the island. A check was made also on data from Spanish writers who gave differing accounts with regard to the former presence of a troglodytic population in the isolated mountains of the southwestern peninsula.

As a further important result, this season's investigations established the identity of the Samaná cave culture, investigated by a Smithsonian expedition in 1928, with the large shell middens on Île á Vache, on the Caribbean coast of Haiti. The same primitive, nonagricultural, non-Arawak Ciboney apparently are also responsible

for the large middens consisting primarily of conch shells (*Strombus gigas*) recently discovered by Doctor Wetmore on Beata Island off the southern coast of Barahona Province, Dominican Republic. Cumulative evidence obtained during the current year and from previous Smithsonian expeditions links the culture of the West Indies with the Arawakan tribes of Venezuela and of the Guianas. There is also data to show that there was no direct tribal contact of these island Arawak with the tribes of southern Florida, although culturally in many ways they were closely associated. There seems to have been a vast overlapping of culture traits of the southeastern United States from the south, these trait complexes centering about the cultivation of maize and the production of pottery. In so far as cassava (yucca) formed a staple food, the former aboriginal culture traits are associated with those of the South American forested tropical lowlands.

As in former years, the expedition headed by Mr. Collins was made possible by a Smithsonian grant, while that of Mr. Krieger was financed by Dr. W. L. Abbott.

From April 21 to June 6, 1931, the assistant curator of archeology, F. M. Setzler, was engaged in archeological investigations in Texas, arranged in cooperation with the Bureau of American Ethnology of the Smithsonian Institution. After briefly examining several sites along the Gulf coast, he excavated four caves and one rock shelter in Presidio County and visited several other caves in that vicinity. From one large cave examples of aboriginal basketry, matting, cradles, sandals, and other materials were recovered. Although this site is only 150 miles east of a marginal Basket Maker culture, no trace was found of these early Southwestern people. The material exhumed by Mr. Setzler differs in some respects from any other in the Museum, and more research will be required before it can be identified definitely. He has prepared a preliminary report on this field work.

Except for two weeks in October, 1930, J. Townsend Russell, jr., collaborator in Old World archeology, spent the year in Europe, where he continued archeological studies and participated in the excavations of the American School of Prehistoric Research at Castel Merle, in the Dordogne, France, and in Czechoslovakia. Toward the close of the fiscal year Mr. Russell was active in details looking toward a cooperative undertaking with the University of Toulouse for excavation of prehistoric sites in France, which will add decidedly to the collections of the National Museum in a field from which our Institution previously has had very little. These investigations are financed by a special fund for work in Old World archeology.

Dr. Aleš Hrdlička, curator of physical anthropology, left in May on a fourth expedition to Alaska, for the purpose of obtaining measurements and, if possible, casts of the few remaining full-blood Aleutians. He expected to work in the region of supposed contact between the Eskimo, the Aleut, and the Indian, and to examine the various mountain passes between Bering Sea and Cook Inlet and the Gulf of Alaska, through which migrations of early man from the Bering Sea area southward may have been possible.

Dr. Paul Bartsch, through the Walter Rathbone Bacon Traveling Scholarship under the Smithsonian Institution, continued field work in the West Indian islands in a study of the terrestrial molluscan fauna of this area, completing a program of travel initiated two years ago. This year efforts were focused on the southern Bahamas, the islands off the south coast of Cuba, and the Cayman group. Doctor Bartsch was accompanied by three assistants, Harold Cluttick, a student of George Washington University; Ray Greenfield, who had been with him two years ago in Cuba; and Alva G. Nye, jr., of Washington. Harold Peters of the Bureau of Entomology, also accompanied the party to collect specimens of avian parasites. The party left Miami, Fla., on June 9, 1930, in the *Island Home*, a 33-ton, shallow-draft vessel. Work was carried through the islands and cays of the southern Bahamas until August 6, and then the party explored the wonderful molluscan fauna of Great Inagua Island, which proved by far the richest of all the Bahamas. On reaching Guantanamo, Cuba, the *Island Home* was pronounced unseaworthy, and another boat the *José Enrique*, a 35-ton sloop with an auxiliary 22 horsepower gasoline engine, was chartered at Santiago. On August 28 the party continued through the keys along the south coast of Cuba, and from September 10 to September 17 was occupied on Cayman Brac, Little Cayman, and Great Cayman islands. Sails were then set for Cuba, and until September 24 the keys along the coast from Cayo Largo to the Isle of Pines were searched. On September 29 the port of Batabano, Cuba, was reached and the collections were shipped by rail to Habana. The expedition returned to Washington on October 3. This cruise yielded a larger amount of molluscan material than any of the previous trips, no less than 250,000 specimens of mollusks being secured, together with many observations on molluscan faunistic relations. Large collections in other groups were also obtained, among them 925 bird skins and 596 reptiles and amphibians, besides a number of live animals, principally reptiles, for the National Zoological Park.

The Rev. David C. Graham, whose explorations in western Szechwan, China, and the neighboring regions of Tibet, have been a feature of these reports for many years, continued work near

Suifu, and forwarded to the National Museum large and important collections numbering in all 62,000 specimens, the greater part consisting of insects. His main trip during 1930 was an excursion into the unknown and difficult country south of Tatsienlu.

Dr. J. M. Aldrich, in continuation of work which has extended over a period of many years, spent part of June and July, 1930, in making collections of Diptera in Idaho, Washington, California, and Colorado. He visited many type localities, and his collections for this season include a larger number of interesting forms than he has obtained before in a like period in the United States.

Dr. Waldo L. Schmitt continued his investigations of the marine fauna at the Carnegie Marine Biological Station, Tortugas, Fla., from July 9 to August 8, 1930, through the cooperation of the Carnegie Institution of Washington, undertaking this year a preliminary investigation of the deeper water readily accessible to the laboratory. Among the prizes brought back were three specimens of the giant isopod *Bathynomus*, the largest specimen being 10½ inches long, and a new portunid crab of the genus *Benthocascon*, a group heretofore known only from a single specimen taken in the Andaman Sea, Indian Ocean.

Dr. H. C. Kellers, United States Navy, through the courtesy of the Naval Observatory and the friendly cooperation of the Navy Department, was again detailed to act as representative of the Smithsonian Institution for the purpose of making biological collections during the United States Naval Observatory eclipse expedition to Niuafoou, nicknamed "Tin-can Island," a partly submerged volcanic crater situated between Samoa and Fiji. His collections include 100 bird skins and over 7,000 alcoholic specimens of various kinds.

Ernest G. Holt, under the auspices of the National Geographic Society, continued explorations along the Venezuelan-Brazilian boundary and returned with valuable collections, principally of birds, reptiles, amphibians, and plants which have been presented to the National Museum by the society. In the preliminary examination of this material many forms not before represented in our collections have been found. The material is particularly welcome, as the Museum has previously had but little from this region.

Because of association in the work of the National Herbarium it is proper to mention field investigations by Mrs. Agnes Chase, of the Department of Agriculture, who collected in the Eastern Shore region of Maryland for the purpose of studying the distribution of certain coastal plain species of grasses, and by Jason R. Swallen, who spent about three months in the region from Tennessee to Texas and northeastern Mexico studying the ranges of grasses.

Gerrit S. Miller, jr., visited Jamaica from February to April with the special object of determining whether or not bones of rodents or other mammals that are now extinct might be found in the village middens of the pre-Columbian Arawaks. Several kitchen middens were investigated and much material bearing on the food habits of the aboriginal inhabitants was obtained. Miscellaneous collections of various kinds also were made, particularly of plants, reptiles, and Arawak artifacts.

Dr. A. Wetmore, accompanied by Frederick C. Lincoln, of the Bureau of Biological Survey, collected from the middle of March until the end of May in Haiti and the Dominican Republic, continuing the biological survey of Hispaniola that has been under way for several years. The first work was done in the region of Fort Liberte in the north, where they were accompanied by S. W. Parish and by M. W. Stirling, Chief of the Bureau of American Ethnology, who were traveling with Mr. Krieger to examine archeological sites that the latter had under investigation in that area. Returning to Port-au-Prince, Doctor Wetmore, through the courtesy of the United States Marine Corps, made a reconnaissance by airplane of the La Hotte Mountains of southwest Haiti, securing information that governed later travel by pack train in this area and the ascent of Pic de Macaya, the highest mountain in this complex. On arrival again at the coast a visit was made to Ile a Vache to supplement collections made there last year by the Parish expedition.

Returning to Port-au-Prince, Doctor Wetmore and Mr. Lincoln traveled by auto through the mountains to Barahona, in the Dominican Republic, where they secured a small sloop and continued to Beata Island, a little-known island where new forms of birds, reptiles, and land shells were obtained and an extensive series of Indian shell mounds was examined. Work in the Dominican Republic was made possible through letters given by General Rafael Trujillo, President of the Republic, to whom all thanks are due for this invaluable assistance.

Edward P. Henderson, assistant curator of mineralogy, under the auspices of the Roebling fund, spent a month in the well-known silver and nickel camps of Ontario, Canada. Starting from Toronto, he first visited the cobalt district, 300 miles to the north, where rich silver masses and their associations were acquired. Sudbury, the most important nickel district in the world, was next visited. Here a quantity of nickel ore and its minerals was obtained. The pegmatite dikes of the Province at Bancroft yielded recently described materials lacking in our collections. The hearty cooperation of the mining companies, quarry owners, and the staff of the Royal Ontario Museum of Mineralogy was largely responsible for the success of

the trip. Later in the year Mr. Henderson made a brief trip to some of the noted mineral localities in North Carolina to obtain material needed for the study of particular problems.

Dr. C. E. Resser spent about four months in the field, working first in the Grand Canyon, in Arizona, under the auspices of the Carnegie Institution. The second phase of his work led diagonally across the State of Arizona on a rapid reconnaissance, followed by a return to the Grand Canyon for further studies. In this he was accompanied by Dr. A. A. Stoyanow, of the University of Arizona, and by members of the Park Service, who aided in his investigations. Early in July, starting from Salt Lake City, where Dr. R. Endo became a member of the party, work began on the local geology about Delta, Utah, where the party was accompanied by Frank Beckwith, with a profitable visit to Zion Canyon. Thence the course lay north to the Tetons and other places in the vicinity of Yellowstone National Park. During investigations at those places, Dr. and Mrs. Curt Teichert joined the party. Rain interfered materially with travel and work; and since matters of moment requiring attention arose at the Museum, work was closed for the season. Travel from Salt Lake City was by truck, the entire trip home being made by this means. The season as a whole was most profitable in the knowledge gained of the various geologic strata, although not many fossils were secured, as the strata studied are for the most part nonfossiliferous.

Since the field exploration in charge of C. W. Gilmore extended into the present year, but brief mention was made of it in last year's report. This exploration in the Bridger (Eocene), in the Bridger Basin, southwestern Wyoming, met with unusual success in the acquisition of large and representative collections. Some of the outstanding specimens have been mentioned elsewhere in this report. The collection as a whole gives the division a good representation of the Bridger fauna and in all probability contains many undescribed forms, being particularly rich in mammals. Its value was further enhanced by the cooperation of Dr. W. H. Bradley, of the United States Geological Survey, who secured the necessary data for a large-scale map, which, with his geological sections, insures the accurate placing of the specimens both geographically and geologically. George F. Sternberg, as in previous seasons, rendered efficient service, and George B. Pierce ably assisted as field assistant. At the close of the fiscal year Mr. Gilmore, again accompanied by Mr. Sternberg, was in the field in Montana and Wyoming.

Although work at the fossil locality near Hagerman, Idaho, was very successful in the season of 1929, the results of the 1930 expedition under Dr. J. W. Gidley exceeded it in both quantity and quality,

as some of the best material found in the deposit was obtained near the close of operations. Camp was established early in May and work was begun where operations had closed the previous season. Two months' additional work fully confirmed the opinion that this fossil bone deposit is one of the most important discoveries in the field of vertebrate paleontology in recent years. Associated with the abundant horse remains were found bones of beaver, otter, mastodon, peccary, and others. The collecting for the season was brought to a close early in July, but the field was still so promising that a third expedition was undertaken in the spring of 1931, under N. H. Boss, chief preparator in the division of vertebrate paleontology. This party was still in the field at the close of the fiscal year so that its results will come properly in the report for next year.

BUILDINGS AND EQUIPMENT

Usual routine repairs have been necessary in connection with the buildings of the National Museum to keep them in proper condition. In the Natural History Building the auditorium was painted, as were also the corridors surrounding it. A considerable amount of painting was done in ranges in halls on the first and second floors, many of which had not been painted since the completion of the building nearly 20 years ago. Metal and wooden window frames were painted, as were also the walls and floors of the engine room. A revolving door was installed at the north entrance, a needed improvement particularly in the winter season.

Steel galleries were erected in two ranges on the ground floor and in certain adjacent rooms that provide housing for the study collections of mammals which have been stored temporarily in two exhibition halls on the second floor. Necessary plans and specifications for this work were prepared by the engineering division of the Office of Public Buildings and Public Parks. The work of erection of the galleries began on April 15, 1931, and was well along toward completion at the close of the fiscal year.

In the Arts and Industries Building various exhibition halls were reconditioned during rearrangement of some of the exhibits, and the women's comfort room was enlarged and remodeled. In the Aircraft Building a sprinkler system and other fire safeguards were installed. The building was repainted within and without and a concrete base was built at the bottom of the sloping sides around the entire exterior.

In the rooms occupied by the National Museum in the Smithsonian Building walls and ceilings in 12 rooms in the division of plants were repainted, and insulating material to control excess summer heat and

excess heat radiation in winter was installed in the ceiling in the main herbarium hall.

The power plant was in operation from September 29, 1930, until May 27, 1931. The consumption of coal during the year was 3,329 tons, at an average cost per ton of $5.65. The amount required was somewhat less than that of last year, due primarily to the mild winter, and secondarily to the fact that some of our electric current was purchased from the Potomac Electric Power Co., thus relieving the load on the boilers at such times as all of the exhaust steam was not needed for heating the Natural History Building. The Steamboat Inspection Service has examined the boilers and the elevators have been regularly inspected by the District of Columbia inspector. The total electric current produced amounted to 613,000 kilowatt-hours, manufactured at a cost of 1.78 cents per kilowatt-hour, including interest on the plant, depreciation, repairs, and material. In addition electric current to the amount of 73,250 kilowatt-hours was purchased and used in the exhibition halls of the Arts and Industries Building. Needs for electrical current are steadily increasing, particularly to provide favorable lighting in our exhibition halls during dark days in winter, and increased purchases will be required in the future.

The ice plant manufactured 406.8 tons of ice, at an average cost of $1.67 per ton, a reduction from the expense for the previous year. With the plant operating at full capacity it is not practicable at the present time to manufacture the entire amount of ice required during the hottest weather of summer, so that it is necessary to purchase a certain amount at that time.

During the year 20 exhibition cases and bases, 439 pieces of storage, laboratory, and other furniture, and 1,667 drawers of various kinds were added, the greater part of these being manufactured in our shops.

MEETINGS AND RECEPTIONS

The lecture rooms and auditorium were used during the present year for 103 meetings, covering the usual wide range of activities. Government agencies that utilized these facilities for hearings, meetings, lectures, and other special occasions included the Bureau of Agricultural Economics, the Plant Quarantine and Control Administration, the Forest Service, the Bureau of Dairy Industry of the Department of Agriculture, and the United States Public Health Service. In addition a meeting was arranged by the Director of Scientific Work of the Department of Agriculture for an address by Dr. Samuel C. May, of the University of California, on the workings of the Government. There were various conferences held from

June 16 to 23 in connection with the Fifth National Farm Girls and Boys 4-H Club Camp. The Department of Agriculture Graduate School also utilized the auditorium for an address by Dr. R. A. Fischer, of the Rothamsted Experiment Station, on statistics. The scientific societies that met regularly in the auditorium or small lecture room included the Vivarium Society, the Entomological Society of Washington, the Society for Philosophical Inquiry, the Anthropological Society of Washington, and the Helminthological Society of Washington. Meetings were also held by the Wild Flower Preservation Society (Inc.), the Audubon Society of the District of Columbia, the Biological Society of Washington, and the Potomac Garden Club.

The National Association of Retired Federal Employees held regular meetings during the year, and there was one meeting of the Smithsonian Relief Association. The National League of Commission Merchants met on December 17 under the auspices of the Bureau of Agricultural Economics for the purpose of explanation of the provisions of the recently enacted perishable agricultural commodities act. The Maryland-Virginia Farmers' Marketing Association met on February 12 to discuss plans for a farmers' market. Dr. Arthur A. Allen, of Cornell University, lectured on February 23 before the Audubon Society of the District of Columbia on native birds and their advantages on golf courses. Dr. Raymond L. Ditmars lectured before the Biological Society of Washington on February 28 on reptiles.

The American College of Physicians during its fifteenth annual clinical session met in the auditorium on March 28 for an address by Dr. Aleš Hrdlička on the diseases of the human race.

On April 13 there was held the eighth national and sixth international oratorical contest for the Evening Star area for contestants from private and parochial schools of Washington. This was followed on May 8 by the second zone finals for the same contest.

On April 28 the Bureau of Dairy Industry, United States Department of Agriculture, held a meeting of the International Association of Milk Dealers. On May 18 the Carnegie Institution of Washington arranged an address by Sir James H. Jeans, of the Royal Society of London, on Out in the Depths of Space. On May 19 there was an address by Dr. M. A. Crossman, of the Republic Research Corporation on Nitriding before the metallurgical advisory committee of the Bureau of Standards and the Washington-Baltimore Chapter of the American Society for Steel Treating.

The seventh annual national spelling bee was held in the auditorium on May 26, when the first prize of $1,000 was won by Ward Randall, of White Hall, Ill.

MISCELLANEOUS

The exhibition halls of the National Museum were open during the year on week days from 9 a. m. to 4.30 p. m., except that the Aircraft Building, as has been noted, was closed for repairs for eight months during the year. Our Museum halls were also open on Sunday afternoons from 1.30 p. m. to 4.30 p. m., with the exception of the Aircraft Building. All buildings remained closed during the day on Christmas and on New Year's.

The flags on the Smithsonian and Museum Buildings were placed at half mast from 1.15 p. m. April 9 through April 11, out of respect for the late Speaker of the House of Representatives, the Hon. Nicholas Longworth. During the forenoon of Memorial Day the flags also were held at half-mast. Visitors for the year totaled 1,669,140, a decrease of a little more than 230,000 from the record of the preceding year, this difference being due partly to the fact that the Aircraft Building was closed for a considerable part of this period. Attendance in the several buildings in the National Museum was recorded as follows: Smithsonian Institution, 258,616; Arts and Industries Building, 731,186; Natural History Building, 631,498; Aircraft Building, 47,840. The average daily attendance for week days was 4,452, and for Sundays 5,472.

During the year the Museum published 7 volumes and 41 separate papers, while the distribution of literature amounted to 86,680 copies of its various books and pamphlets. Additions to the Museum library, obtained partly by exchange, partly by donation, and partly by purchase, included 2,528 volumes and 832 pamphlets, an increase over those of the previous year. The library of the National Museum, as separate from that of the Smithsonian Institution proper, now contains 79,407 volumes and 109,129 pamphlets. Much progress was made during the year in the arrangement and cataloguing of these collections, not only in the main libraries but also in the 36 sectional libraries of the organization. Duplicate volumes in our series have been assembled and many have been distributed to other organizations, either as gifts or as exchanges.

On March 5, 1931, John E. Graf was appointed associate director of the National Museum under the assistant secretary. Mr. Graf came to the Museum by transfer from the Department of Agriculture, where he had long been connected with the administration of the Bureau of Entomology, in recent years as assistant chief.

In the department of anthropology the former divisions of American archeology and of Old World archeology were consolidated on February 1, 1930, as a division of archeology, under Neil M. Judd as curator.

On February 1, 1931, Dr. A. J. Olmsted, chief photographer, was appointed assistant curator of the section of photography under the division of graphic arts.

Frank M. Setzler was appointed assistant curator of the division of archeology, August 16, 1930, and Gustav A. Cooper, assistant curator in the division of stratigraphic paleontology on October 20, 1930.

Following the retirement of Dr. Marcus Benjamin, Paul H. Oehser was appointed Museum editor on April 16, by transfer from the Department of Agriculture. Miss Gladys O. Visel was transferred on March 1 from the National Gallery of Art to become clerk in the Museum editorial office, and Frank W. Bright, of the Government Printing Office, on March 2 succeeded J. C. Proctor, retired, as compositor in the branch printing office of the Museum. Effective March 1, 1931, the editorial work of the entire Institution was consolidated in one central office under W. P. True, editor of the Smithsonian Institution.

January 1, 1931, Lester E. Commerford became assistant chief in the office of correspondence and documents.

The following employees left the service through operation of the retirement act: Dr. Marcus Benjamin, editor, on January 31, 1931, after a service begun April 1, 1896. During Doctor Benjamin's incumbency there were published under his editorship 31 annual reports, 59 volumes of proceedings, and 106 bulletins, many of the latter in several volumes, a long and remarkable record. John Claggett Proctor, printer, retired February 28, 1931, after a service of 46 years.

On August 31, 1930, the following left the service through operation of the retirement act: Dr. James E. Benedict, assistant curator in the department of biology, after over 40 years of active service in many varied fields in the Museum, particularly with regard to our exhibits in biology; Miss Nellie H. Smith, clerk in the administration office since April, 1890; J. W. Scollick, osteologist since July, 1884; John S. Prescott, electrician since January, 1896; William O. Murray, skilled laborer, after 11 years' service. John M. Mohl, electrician's helper, was retired on March 31 after over 33 years of service. Jerome Patterson, watchman, was retired for disability on June 17, 1930. Through death the Museum lost three workers from its active roll, Miss Narcissa Owen Smith, January 31, 1931; Paul Schilke, watchman, on January 1, 1931; and Robert L. Belt, watchman, on February 4, 1931.

From its honorary list of workers the Museum lost by death Isobel H. Lenman, honorary collaborator in ethnology, on February 3, 1931.

Dr. Frank Wigglesworth Clarke, honorary curator of mineralogy since December, 1883, died May 23, 1931. There may be mentioned further the death on November 2, 1930, of Dr. Oliver Perry Hay, internationally known for his work on paleontology, who, though never officially attached to the staff, carried on his researches in the Museum for nearly a quarter of a century.

Respectfully submitted.

ALEXANDER WETMORE,
Assistant Secretary.

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit herewith my report on the operations of the National Gallery of Art for the fiscal year ending June 30, 1931:

PRESENT DISTRIBUTION OF THE ART COLLECTIONS

In 1920 the art collections of the Institution, so far as they had been assigned to the care of the recently established National Gallery of Art, were installed in the central skylighted hall of the new Natural History Building of the National Museum. This hall extends from the rotunda on the south to the north front of the building, the windows of which look down on Constitution Avenue. Permanent screens were introduced in this hall affording excellent hanging space for the paintings. The disposition then made of the numerous groups of art works has been changed from time to time and important groups have been added. During the 10 years that have passed slight record of the placement of these collections has been kept, and it may be advisable to indicate here briefly the present distribution.

The Harriet Lane Johnston collection, an early bequest of great value, comprising paintings and historical documents, is installed in the northwest long room of this hall. Across the hallway from this collection, occupying the northeast long room, is the Ralph Cross Johnson gift of rare European old masters, presented in 1919.

Distributed through a number of rooms, including the large central gallery, are numerous groups of works by our American masters. Prominent among these is the great gift of 152 paintings, representing 106 artists, by William T. Evans, of New York. The Alfred Duane Pell collection of art objects of varied types and much interest is accommodated in the north extension and hallway at the north end of the hall. A number of the larger works of both paintings and sculptures are installed in available spaces in the rotunda.

On the ground and first floors are several groups of historical paintings. First among these is the group of World War portraits. Shortly after the close of the World War a number of Americans organized a national art committee, the purpose of which was to obtain portraits for the National Gallery of Art of a number of distinguished leaders of the allied forces. Entering this hall from the

north the visitor finds himself face to face with many of the outstanding personages of the great war—kings, queens, presidents, soldiers, statesmen, and others—whose faces and achievements are familar to the peoples of every civilized nation.

Occupying the walls of a large room on the second floor is the collection of portraits of survivors of the Civil War painted from life by Walter Beck 50 years after the close of the war. Associated with this group are two other World War groups, the John Elliott collection of portraits of young Americans who entered the air service of France before the United States had decided to take part in the war, many of these losing their lives in the struggle; and a very interesting collection of sketches of prominent World War personages made by John C. Johansen for use in executing his great work, the "Signing of the Peace Treaty, June 28, 1919," now occupying the west wall of the lobby. In the lobby are assembled also numerous busts and other works of sculpture, while a number of paintings embellish available spaces on the walls of the stairway. The Freer collection, the most important single unit of the gallery's possessions, occupies a commodious building immediately west of the Smithsonian provided by the donor. The recently acquired Gellatly collection of art works of wide scope and great value is retained, as originally installed by the donor, in the Heckscher Building, New York City, due to lack of gallery space in Washington; while the large collection of drawings by John S. Sargent (1856–1925), a gift from his sisters Miss Emily Sargent and Mrs. Violet Ormond, remain in storage at the Corcoran Gallery of Art for the same reason.

THE GALLERY COMMISSION

The tenth annual meeting of the National Gallery of Art Commission was held in the Regents' room of the Smithsonian Institution at 10.30 o'clock, December 9, 1930. The members present were: Gari Melchers, chairman; Frank J. Mather, jr., vice chairman; W. H. Holmes, secretary; Herbert Adams, James E. Fraser, J. H. Gest, John E. Lodge, Charles Moore, E. W. Redfield, and Dr. Charles G. Abbot, ex officio.

The minutes of the last annual meeting, held December 10, 1929, were read and approved. The annual report of the secretary of the commission reviewing the activities of the gallery for the calendar year 1930 was read and accepted.

After careful inspection, a portrait of Commodore Stephen Decatur, by Gilbert Stuart, bequeathed to the National Gallery by the late William Decatur Parsons, and an enamel watch by Loulinie & Legandroy, Geneva, Switzerland, bequeathed to the Institution by Miss Charlotte Arnold H. Bryson, were accepted by the commission.

THE ABNEY BEQUEST

Doctor Abbot made the following statement: Under the will of Mrs. Mary Lloyd Pendleton Abney, of New York, dated May 16, 1928, the following bequest is made:

Clause—

Seventh. To the National Gallery, at Washington, D. C., heretofore known as the Corcoran Gallery, I give and bequeath the four Key family portraits said to have been painted by Peter Lilly and Godfrey Kneller, to wit, portraits of Mrs. John Zouch (Lady Zouch); Michael Arnold; Ann Arnold, wife of Michael Arnold and daughter of Thomas Knipe; and Susan Gardner, the mother of John Ross; and I give and bequeath also the portrait of Mary Tayloe Lloyd, wife of my grandfather, Francis Scott Key, painted by Godfrey Kneller, and her miniature, painted by Robert Field; the Key table, and two chairs which were used by Francis Scott Key; the Lloyd mahogany table and four old chairs and old knocker from the Francis Scott Key house, which was at Georgetown, by the Arlington Bridge, now known as the Key Bridge. * * *

(Note by the executrix: Mrs. Abney, while living donated and delivered to others the furniture mentioned in clause 7, and the "old knocker" was not found among her effects.)

[Doctor Abbot, Secretary of the Smithsonian Institution, has been informed by Mrs. Jane F. Brice, the sister and executrix of Mrs. Abney, that the Corcoran Gallery has executed waiver to any right it might have to the bequest, and the matter was presented by her to the director of the National Gallery, with the oral request, by her husband, to have the National Gallery also execute a waiver of its rights.

The matter was laid before the permanent committee of the Board of Regents. Having in mind the probable value and interest of the objects, both from the artistic and historical standpoints, and in view of the national character of the gallery, the committee did not feel that on the ex parte statements of the executrix, who is also the residuary legatee under the will, they could waive any rights that the gallery might have, without a proper adjudication of the matter, and so informed Mrs. Brice. The matter is now before the court.]

THE RANGER COLLECTION

At the request of the chairman, James E. Fraser read a report that had been made to the council of the National Academy regarding the selection of the Ranger pictures to be retained by the National Gallery.

After full discussion in which it developed that the commission was not to be asked to take any official action, Mr. Gest submitted the following resolution, which was adopted:

Resolved, That the thanks of the commission be tendered Mr. Fraser for his comprehensive statement and that the paper be included in the records of this meeting as a matter of information.

THE WASHINGTON BICENTENNIAL CELEBRATION

Herbert Adams brought up the matter of the Washington bicentennial celebration planned for 1932, saying that the Sculpture Society had suggested a comprehensive scheme for the exhibition of paintings and sculptures pertaining to Washington. The matter was discussed at some length, and Mr. Moore stated that the Bicentennial Commission had this matter in hand and that the commission would probably address a letter to the secretary of the Institution on the subject.

ELECTIONS

The secretary was directed to cast a ballot for the reelection of Gari Melchers, chairman; Prof. F. J. Mather, jr., vice chairman; and William H. Holmes, secretary.

The secretary called attention to the fact that the terms of three members of the commission would expire on December 14. Mr. Fraser submitted the following resolution which was adopted:

Resolved, That the commission recommend to the Board of Regents the reelection for the succeeding term of four years of the following members: Herbert Adams, Gari Melchers, and Charles Moore.

There being no further business to come before the meeting, the commission adjourned at 12 o'clock.

EXHIBITIONS HELD IN THE GALLERY

1. A collection of 78 masterly water colors of Asiatic, European, and American Indian subjects, by William Spencer Bagdatopoulos, the Greek-English artist, was shown in the two northern small rooms of the gallery October 30 to December 22, 1930. A catalogue was supplied by the gallery.

2. A memorial exhibition of water colors of Egyptian, Greek, French, Italian, and English subjects, by Henry Bacon, was installed in the large middle room of the gallery March 14 to April 30, 1931. The collection proved of exceptional interest. A catalogue was supplied by the gallery.

3. The fortieth annual exhibition of the Society of Washington Artists, the second held in the gallery, occupied the walls in the central group of rooms, main floor of the gallery, February 1 to March 1, 1931. The exhibition included 162 paintings and 21 works of sculpture and received flattering public attention. An illustrated catalogue was supplied by the society.

THE GALLERY CATALOGUE

Two catalogues of the art collections of the Institution have been published as Bulletin 70 of the United States National Museum, the first edition in 1906 and the second in 1916, by Richard Rathbun,

assistant secretary of the Institution, and two catalogues of the National Gallery of Art, the first edition in 1922 and the second in 1926, by the director.

During the year the director has devoted his energies largely to the preparation of a comprehensive catalogue of the art works of the Institution, giving especial attention to works of painting and sculpture. This catalogue does not include the wide range of minor art works usually included in museums of art; and since no definite line has yet been drawn between assignments to the gallery and those that properly pertain to the Museum, the limits of the catalogue must remain indefinite.

The form of the catalogue has received very especial attention. The cards used measure 8 by 10½ inches, corresponding thus to the standard manuscript sheets of the Institution. Each unit or card of the catalogue comprises two somewhat rigid sheets, one devoted to a record of the source of the work and to the biography of the artist and the other to a picture of the work itself. Some 600 cards are now completed. The portrait group comprises about one-third of this number. These are separately assembled owing to the anticipation that the Institution may find it possible, in the near future, to organize a national portrait gallery, and possibly at least to print separately this portion of the catalogue of the art works of the Institution.

Portraits of several types are included in the catalogue approximately as follows:

1. Oil paintings.
2. Water colors.
3. Pastel and related technique.
4. Engravings.
5. Sculpture.

PROFESSOR HOLMES AND THE SMITHSONIAN INSTITUTION

It may not seem out of place, since the director's official life is nearing its close, to record here briefly his connection with the Smithsonian Institution. Just 60 years ago he entered the north door of the Institution an entire stranger and proceeded to sketch a brilliantly colored bird installed in one of the Museum cases. He was observed at this work, and as a result was soon engaged in drawing natural history specimens for the resident professors. In 1872 he was appointed artist to the survey of the Territories and took part in the survey of the Yellowstone region. In 1874 he was appointed assistant geologist on the survey then working in Colorado and has found his services continuously called for in the fields of both science and art. Advancing step by step and from year to year in both branches, he finds himself to-day a member of the National Academy

of Sciences and Director of the National Gallery of Art. His varied activities in these fields are recorded in upward of 50 annual reports made to the departments with which he served.

ART WORKS RECEIVED DURING THE YEAR

Accessions of art works by the Smithsonian Institution, subject to transfer to the National Gallery on approval of the advisory committee of the National Gallery of Art Commission, are as follows:

Portrait statue (heroic size, full length) of Col. Archibald Gracie, 4th, hero of the *Titanic* disaster, 1914, by Louise Kidder Sparrow. Gift of Mrs. Archibald Gracie, 4th.

Portrait of Commodore Stephen Decatur by Gilbert Stuart; bequeathed to the Smithsonian Institution for the National Gallery of Art by the late William Decatur Parsons. (Accepted by the commission December 9, 1930.)

Portrait of Henry Ward Ranger by Albert Niehuys (Dutch artist); presented by Frederick Ballard Williams, N. A.

Original plaster bust of Abraham Lincoln (heroic size) from which was cast the bronze bust erected at the National Cemetery, Gettysburg, Pa., by Henry K. Bush-Brown; gift of the sculptor. This bust has been in the gallery for several years as a loan.

A group of three wood-gravure tablets engraved directly from life and nature by Macowin Tuttle: Portrait of a Lady, Snowbound (winter landscape), and Spring Brook (spring landscape). Gift of Mr. Tuttle.

Painting entitled "Late Afternoon, the Alcazar, at Segovia, one of the picturesque medieval castles of Spain," by Wells M. Sawyer. Gift of the artist.

Marble bust of William H. Seward, made in Rome in 1871 by Giovannie Maria Benzoni (1809–1873), "as a gift in memory of his daughter, Olive Risley Seward"; also the framed oil painting by Emanuel Leutze (1816–1868), sketch from which he made the fresco in the Capitol Building at Washington, D. C., known as "Westward the Course of Empire Takes its Way," and presented to William H. Seward by the artist. Bequest of Miss Sara Carr Upton.

Portrait of William Henry Holmes, first director of the National Gallery of Art, by William Spencer Bagdatopoulos in 1929; presented by the artist.

LOANS ACCEPTED BY THE GALLERY

Painting by Bonifaccio entitled "Supper at Emmaus"; lent by Benjamin Warder Thoron, of Washington, D. C., through Mrs. Henry Leonard.

Portrait of Henry Ward Ranger, N. A., by Alphonse Jongers, N. A.; lent by the Council of the National Academy of Design, New York, N. Y.

Fifteen paintings by British and Dutch masters; lent by Cleveland Perkins, Esq., Miss Ruth Perkins, and Mrs. Miriam Perkins Carroll, executors of the estate of the late Henry Cleveland Perkins, as follows:

Portrait of a Boy, by John Hoppner, R. A.
Henry, First Earl of Mulgrave, by Sir Thomas Lawrence, P. R. A.
Portrait of a Dutch Lady, by Michael Janson Mierevelt.
Portrait of a Dutch Girl, by P. Moreelse.
Portrait of a Girl, by John Opie, R. A.
Frances, Countess of Clermont, by Sir Joshua Reynolds.
The Windmill, by Salomon Ruysdael.
Study of Ruins, by Richard Wilson.
Study of Ruins, by Richard Wilson.
Landscape, by Richard Wilson.
Landscape with Cottage, by Meindert Hobbema.
Madonna and Child, by Van Dyck (attributed to).
Portrait of a Dutch Girl, by Jan Victoors.
A Gentleman, by Sir William Beechey, R. A.
A Cottage Scene, by Ladbrooke.

Five paintings by old masters; lent by Mrs. Marshall Langhorne, Washington, D. C., as follows:

Holy Family, by M. Albertinelli.
Head of Christ, by Giorgioni (attributed to).
The Doctor's Visit, by Jan Steen.
Baptism of Christ, by G. B. Tiepolo.
Small landscape, by Thomas Gainsborough.

Portrait of George Washington, by Charles Willson Peale; lent by William Patten, of Rhinebeck, N. Y., to be cared for until used by the George Washington Bicentennial Commission.

A Sevres porcelain statuette, by Paul Dubois, entitled "Le Courage Militaire"; lent by the Hon. Hoffman Philip, United States minister to Norway.

A painting, Madonna and Child, by Andrea del Sarto; lent by Mrs. W. W. Powell, Washington, D. C.

A pastel, A Madonna and Child, conception of F. D. McCreary, executed by Pastelist Bryson, of Chicago, Ill.; lent by Mrs. B. S. Williams, of Knoxville, Tenn.

Usual loans of paintings for the summer months are:

Portrait of George Washington, by Rembrandt Peale; lent by the Hon. Charles S. Hamlin, Washington, D. C.

Portrait of Nathaniel Tracy, of Newburyport, Mass., by John Trumbull; portrait of Thomas Amory, of Boston, and portrait of George A. Otis, both by Gilbert Stuart; lent by Mrs. O. H. Ernst and Miss Helen Amory Ernst, of Washington, D. C.

Portrait of Mrs. Charles Eames, by Gambardella; lent by Mrs. Alastair Gordon-Cumming, of Washington, D. C.

DISTRIBUTIONS

A painting, The Battle of Celere, by J. C. Bourgignon; withdrawn by the owner, Mrs. J. M. Wiley, for shipment to Holland.

The large painting by Theobold Chartran, of Paris, representing the Signing of the Peace Protocol between Spain and the United States, August 12, 1898, lent to the gallery in 1928, has been recalled to the White House by Mrs. Hoover.

The painting by Peter Moran, entitled "A Rainy Day," withdrawn by the owners, Miss Florence Grandin and her sister, of Washington, D. C.

Two small paintings by John J. Peoli, entitled "Love Conquers" and "Cupid Caged," were returned to Mrs. Laura Guiteras, Denver, Colo., residuary legatee of the estate of Mrs. Mary Peoli Maginn.

A painting, Salome with the Head of John the Baptist, attributed to Guido Reni, was withdrawn by J. H. Weaver, of Washington, D. C., to whose ownership it had been transferred by Hobart Berriman.

A painting, The Infant Jesus and St. John, by Rubens, lent to the gallery by Hon. Hoffman Philip in 1919, withdrawn by Mr. Philip.

A painting, Minerva (sixteenth century original), was withdrawn by Miss May Warner.

LOANS RETURNED TO THE GALLERY

Mrs. Herbert Hoover returned to its place in the gallery the painting by Alexander Wyant, entitled "The Flume, Opalescent River, Adirondacks," which was lent for temporary display at the White House early in 1929.

THE HENRY WARD RANGER FUND PURCHASES

The paintings purchased during the year by the Council of the National Academy of Design from the fund provided by the Henry Ward Ranger bequest, which under certain conditions are prospective additions to the National Gallery collections, are as follows, including the names of the institutions to which they have been assigned:

Title	Artist	Date of purchase	Assignment
81. The Countryside in Autumn.	Charles H. Davis, N. A.	December, 1930	Connecticut Agricultural College, Storrs, Conn.
82 The Sermon	Gari Melchers, N. A.	January, 1931	The Corcoran Gallery of Art, Washington, D. C.
83. The Offering	Charles Webster Hawthorne, N. A. (1872–1930).	February, 1931	The Cleveland Museum of Art, Cleveland, Ohio.
84. The Madonna	Ivan G. Olinsky, N. A.	March–April, 1931	Everhart Museum of Natural History, Science, and Art, Scranton, Pa.

The gallery has received two portraits of Henry Ward Ranger (already mentioned): One, by Alphonse Jongers, N. A., as a loan from the National Academy of Design; the other, by Albert Niehuys, as a gift from Frederick Ballard Williams, N. A., assistant treasurer of the academy.

The will of Henry W. Ranger provides that the National Gallery of Art shall have the right to reclaim any picture for its collection during the 5-year period beginning 10 years after the artist's death and ending 15 years after his death, and it may be interesting to list the deceased artists to June 30, 1931.

Artist	Date of death
1. Carlton T. Chapman, N. A	Feb. 12, 1925.
2. Dwight W. Tryon, N. A	July 1, 1925.
3. William A. Coffin, N. A	Oct. 26, 1925.
4. Ben Foster, N. A	Jan. 28, 1926.
5. Thomas Moran, N. A	Aug. 26, 1926.
6. H. Bolton Jones, N. A	Sept. 24, 1927.
7. Robert Reid, N. A	Dec. 2, 1929.
8. Gardner Symons, N. A	Jan. 12, 1930.
9. Charles W. Harthorne, N. A	Nov. 29, 1930.

LIBRARY

The gallery library continued to increase by gift, purchase, and subscription, in volumes, pamphlets, periodicals, etc. Fifty-one volumes of periodicals were collated and bound.

Notable accessions to the library are as follows:

A tinted pencil-drawing in miniature of Dr. William H. Holmes by Alyn Williams, P. R. M. S., R. C. A., presented by the artist.

Eleven bound volumes of biographical memoirs called Random Records, left-over remnants from 52 years of research and art work in many fields; gift of W. H. Holmes.

Twelve large framed water-color paintings by W. H. Holmes; gift of the artist:

1. Deserted Bed of a Glacier.
2. The Unmodified Rock Creek about 1910.
3. The Normal Rock Creek About 1910.
4. Over the Maryland Fields.
5. My Old Mill, Holmescroft, near Rockville.
6. A Storm-Beaten Course.
7. A Maryland Wheat Field.
8. A Maryland Meadow, Watt's Branch, near Rockville.
9. A Gypsy Camp.
10. A Cliff Dwellers' Ceremony, Colorado.
11. A Mountain Gorge, Colorado.
12. Coal Barge, Capri, 1880.

Fourteen water-color paintings of diversified subjects by W. H. Holmes; gift of the artist. (These include the 12 noted in the 1927 annual report.)

A Pompeiian Fountain, 1880.
On the Ocean, off Nova Scotia, 1880.
A Color Study, Venetian Freight Boats.
Longs Peak, Colorado, 1874.
A Great Geological Arch, Colorado, 1874.
The Land of the Cliff Dwellers, 1874.
In the Pueblo Country, New Mexico, 1876.
A Mexican Laundry, 1895.
Playing with the Colors.
Shaded Pathways.
View on the Potomac.
The Fields of Maryland.
Study of a Bridge.
Still Life—Apple and Bottle.

Ten field sketches, of small size, by Thomas Moran; pen sketch by Mrs. W. H. Holmes; and a sketch in Florida (in colors) by Walter Paris; gift of W. H. Holmes.

Twenty-nine small, unframed paintings in different mediums by 20 artists; gift of W. H. Holmes.

1. A Neopolitan Lady, by C. Bisco.
2. Marine Study, by Franklin D. Briscoe.
3. Burial of a Pappoose, probably Siouan, by Richard N. Brooke.
4. Drawing of a Yellowstone Geyser, by Richard N. Brooke.
5. Landscape Sketch, by J. F. Currier.
6. Burning of an Old Boat, by F. Denby, A. R. A.
7. A Group of Elk, Wind River Mountains, Wyoming, by E. W. Deming.
8. French Village Scene, by H. A. Dyer.
9. Landscape, by De Lancey Gill.
10. Landscape Sketch, by De Lancey Gill.
11. Naples and Vesuvius, by A. Gurri.
12. Sketch on the Potomac, by Lorenzo J. Hatch.
13. In the Plateau Country—Colorado, by W. H. Holmes.
14. Marine View, by "Marnz."
15. Landscape with Palm Trees and Temple, Egypt, by Charles M. McIlhemey.
16. Shin-Au-Av-Tu-Weap—God Land Canyon of the Colorado, Utah, by Thomas Moran.
17. In Monument Park, Colorado, by Walter Paris.
18. Landscape, by Walter Paris.
19. Study of a Courtier, by Randonini.
20. Landscape Sketch, by Walter Shirlaw.
21. Figure Study, by Walter Shirlaw.
22. A Study of an Italian Peasant Woman, by Guisep Signorini.
23. Study of an Old Man, by Guisep Signorini.
24. Sketch in Wales, by Peter Toft.
25. Group of Venetian Sailboats, by Ross Turner.
26. Charcoal Boat on the Mediterranean, by Ross Turner.
27. Venetian Boats, by Ross Turner, 1880.
28. A Street Scene in Munich, by Ross Turner, 1880.
29. A Tree Study, by Ross Turner, 1879.

NECROLOGY

The death of James Parmelee at his home in Washington, D. C., on April 19, 1931, is announced. Mr. Parmelee was a member of the National Gallery of Art Commission, one of the commission's executive committee, and chairman of the committee on prints.

A biographical notice of Mr. Parmelee may be found in the Cathedral Age, midsummer issue, 1931, page 28.

PUBLICATIONS

Holmes, W. H. Report on the National Gallery of Art for the year ending June 30, 1930. Appendix 2, report of the Secretary of the Smithsonian Institution for the year ending June 30, 1930, pp. 45–53.

Lodge, J. E. Report on the Freer Gallery of Art for the year ending June 30, 1930. Appendix 3, report of the Secretary of the Smithsonian Institution for the year ending June 30, 1930, pp. 54–60.

Catalogue of a collection of water-color paintings by W. S. Bagdatopoulos, on view in the National Gallery of Art, United States National Museum, October 30 to December 22, 1930. Pp. 1–8.

Catalogue of a memorial exhibition of water colors of Egypt, Greece, France, Italy, and England, by Henry Bacon (1839–1912), on view in the National Gallery of Art, United States National Museum Building, March 14 to April 30, 1931. Pp. 1–9, 4 pls.

Fortieth annual exhibition of the Society of Washington Artists, being a list of the titles and authors of the works shown, with an introduction by Dr. William H. Holmes, Director of the National Gallery of Art. Privately printed for the society, 1931. Pp. 1–30, 20 pls.

Respectfully submitted.

W. H. Holmes, *Director.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the eleventh annual report on the Freer Gallery of Art for the year ending June 30, 1931:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BRONZE

31.10. Chinese, fifth century B. C. Chou Dynasty. Ceremonial vessel of the class *i*, with four handles. Green patina.

JADE

31.15–31.16 Chinese, Han Dynasty (206 B. C.–A. D. 220). Two ornaments of white, semitranslucent jade, surface color altered to a brownish cream. Decoration carved and engraved.

MANUSCRIPTS

30.86. Nepalese, twelfth century. The *Prajñāpāramitā.* Palm leaves (69) within wooden covers. (See also below under *Paintings*, 30.87, 30.88.)

30.92–30.95 Persian, thirteenth century. Four leaves from a *Qurān* (miniature size). Text in brown *naskhī* script.

31.9. Arabic (North Africa), twelfth century. A bound volume of a section of the *Qur'ān.* Vellum. Text in brown and blue *Maghribī* script; page and text ornaments in gold and slight color.

31.11. Persian, sixteenth century. A page from the *Gulistān* of Sa'adī, written in a delicate *naskhī* script on light blue paper; five ornaments in gold and color.

PAINTINGS

30.80. Chinese, fifteenth century. Ming. By Tai Chin. A landscape entitled "Life on the river." Silk scroll, painted in ink and tint.

30.81. Indian, late sixteenth century. Rajput, Rājasthānī. A musical mode (*rāg*) : a night scene. Color on paper.

30.82. Indian, early nineteenth century. Rajput, Pahāṛī (Kāngṛā). Portrait of a lady. Color and gold on paper.

30.83. Indian, early nineteenth century. Rajput, Pahārī (Kāngrā). Śrī Krishna fluting in the forest. Color and gold on paper.

30.84. Indian, early nineteenth century. Rajput, Pahāṛī, (Kāngṛā). Maidens searching for Krishna in moonlight. Color and gold on paper.

30.85. Indian, eighteenth–nineteenth century. Rajput, Pahārī (Kāngṛā). Scene from a Nala-Damayantī series: The toilet of Damayantī. Outline drawing and light tints on a primed paper.

30.87–30.88. Nepalese, twelfth century. Two pages, each containing three miniatures from the *Prajñāpāramitā* (MS. 30.86; see above). Opaque colors on palm-leaves.

30.89–30.90–30.91. Persian, fourteenth century. Mongol period. Three pages from a *Shāhnāmah*. Color, black and gold on a gold ground. Text in black *naskhī* script.

31.1. Chinese, fourteenth century. Yüan dynasty. By Tsou Fu-lei. Plum branches in flower, entitled, "A breath of spring." A scroll painting; ink on paper. Signed.

31.2. Chinese, thirteenth century. Late Sung. By Wang Yen-sou. Branches of a plum tree in flower, entitled, "Plum blossoms." Scroll painting; ink on silk. Signed.

31.3. Chinese, thirteenth century. Late Sung. Landscape; horses and grooms crossing a river. Scroll painting; color and ink on paper.

31.4. Chinese, fourteenth century. Yüan. Attributed to Chao Mêng-fu. A goat and a sheep. Scroll painting; ink on paper. Signed.

31.5–31.6. Indian, early seventeenth century. Mughal. School of Akbar. Two illustrations from *Rasikapriyā* MS. Color and gold on paper.

31.12. Persian, late sixteenth century. Portrait of a lady. Ink, slight tint and gold, on paper.

31.13. Persian, middle sixteenth century. Portrait of a man. Full color and gold on paper.

31.14. Persian, middle sixteenth century. Portrait of a youth, reading. Full color and gold on paper.

POTTERY

31.7. West Asian, eleventh–twelfth century. Rakka. A star-shaped lamp, with six spouts and six feet. Light blue-green glaze, worn and crazed.

SILVER

31.8. Chinese eighth century. T'ang dynasty. Bowl, decorated with a band of foliate design in low relief. Surface covered by a delicate ornament executed in fire gilt.

Curatorial work within the collection has embraced specifically the study and recording of inscriptions and seals on recently acquired Chinese paintings and of Buddhist inscriptions on stone sculptures and votive bronze images. The work of cataloguing the near eastern section of manuscripts and paintings, mentioned as being under way in the last report, has been completed. Translation of the Persian texts has fixed the identity of upwards of 60 Persian miniatures taken from various early manuscripts of the *Shāhnāmah*, the *Gulistān* of Sa'adī, and other works. In addition to translations of inscriptions on objects in the Freer collection others have been made of inscriptions on objects submitted to the curator by other institutions and by private persons for expert opinion as to their esthetic or historical value. In all, 2,312 objects and 107 photographs of objects were submitted for examination.

The most important changes in exhibition that have been made since 1923 were accomplished during the week of March 15, amounting to the opening of four new galleries and changed exhibitions in two others. Galleries I and II, at the right of the entrance, are now devoted to the display of works of art from the Near East and India. Included in these are early Arabic manuscripts and paintings, Arabic tooled leather bindings, Persian manuscripts, paintings and painted pottery, Indian painting and sculpture. This change has not only given increased space to the near eastern section but also has left the eastern end of the building to the exclusive exhibition of the arts of China. Ancient bronzes, silver, and silver-gilt are now displayed in Gallery XIV, ceremonial and ornamental jades of the Chou and Han periods in the adjoining corridor. Gallery XVIII exhibits scroll paintings and Gallery XIX pottery, porcelain, and panel paintings.

The care and preservation of objects in the collection has included work that can be itemized as follows:

(1) Remounted:
- 2. Chinese scroll paintings.
- 1 Chinese panel painting.
- 2 Japanese screen paintings.
- 6 Indian miniature paintings.

(2) Repaired (i. e., relined, remounted, or resurfaced):
- 22 paintings by Whistler.
- 2 paintings by A. H. Thayer.
- 2 paintings by T. W. Dewing.
- 2 paintings by D. W. Tryon.
- 2 paintings by G. Melchers.
- 1 painting by J. S. Sargent.
- 1 painting by A. Ryder.

Changes in exhibition have involved a total of 482 objects, as follows:

9 American paintings.
50 Chinese bronzes.
13 pieces of Chinese silver-gilt.
135 Chinese jades.
19 Chinese scroll paintings.
15 Chinese panel paintings.
10 pieces of Chinese porcelain.
59 pieces of Chinese pottery.
2 Japanese screen paintings.
4 Japanese panel paintings.
48 pieces of near eastern pottery.
1 Turkish pottery tile.
12 Arabic and Egyptian bookbindings.
2 Indian stone sculptures.
101 Indian and Persian paintings and calligraphies.
2 pieces of Persian glass.

THE LIBRARY

During the year there have been added to the main library 61 volumes, 20 unbound periodicals, and 150 pamphlets. Twenty volumes were sent to the bindery, 10 volumes to be bound, 4 volumes to be repaired, 48 numbers of *Kokka* to be bound in 4 volumes, and 6 numbers of *T'oung Pao* to be bound in 2 volumes. A list of the new accessions to the library accompanies this report as Appendix A (not printed).

The library is in process of being catalogued under the direction of the librarian of the Smithsonian Institution, W. L. Corbin. This work was begun in November, 1929, and is not yet completed.

REPRODUCTIONS AND PAMPHLETS

Seven hundred and sixty-four new negatives of objects have been made. Of these, 329 were made for registration photographs, 435 for special orders and 67 for study purposes. The total number of reproductions available either as carbon photographs or as negatives from which prints can be made upon request is now 3,858. Twenty-four additional post cards have been published, making a total number of 96 subjects now on sale. One hundred and nineteen lantern slides have also been added to the collection, making a total of 1,030 available for study and for sale.

The total number of sales of reproductions, at cost price, is as follows: Photographs, 1821; post cards, 15,489; lantern slides, 12.

Of booklets issued by the gallery, the following were sold at cost price:

F. G. A. pamphlets	117
Synopsis of History pamphlets	105
List of American paintings	37
Annotated outlines of study	17
Gallery books	204
Floor plans	18

BUILDING

The workshop has been constantly occupied with the making of necessary equipment, as well as with the work necessary to the upkeep of the building. Under the latter the most important item was the renewal of the attic shade system with new and better operating parts and a complete set of new curtains. A new device for holding the smaller paintings to be photographed, four new exhibition cases, two bookcases, and additional frames for the card display are among the items of new equipment. The report of the superintendent, which gives a detailed account of shopwork and of the planting in the court, accompanies this report as Appendix C (not printed).

ATTENDANCE

The gallery has been open every day from 9 until 4.30 o'clock with the exceptions of Mondays, Christmas Day, and New Year's Day.

The total attendance for the year was 125,789; the total attendance for week days was 82,574; the total Sunday attendance 43,215. As before, the average Sunday attendance is much more than twice that of week days, 831 being the average for Sunday and 318 that for a week day. Attendance reached its height in April and August with totals of 23,401 and 14,950, respectively.

The total number of visitors to the offices was 1,510. Of these, 91 came for general information, 295 to call upon members of the staff, 119 to see objects in storage, 100 to submit objects for examination, 74 to study the building and installation methods, 11 to visit the galleries on Mondays, 216 to study in the library, 203 to see the reproductions of the Washington Manuscripts, 19 to make photographs and sketches, and 16 to make tracings, while 229 came to purchase photographs, and 137 to examine photographs of objects in the collection.

Fifty-two groups, ranging from 2 to 47 persons, were given docent service in the exhibition galleries, and 10 classes in groups ranging from three to nine persons were given instruction in the study room.

On Thursday, March 12, 1931, Dr. Rudolf Meyer Riefstahl gave an illustrated lecture on Islamic Painting before an audience of 163 persons.

FIELD WORK

A general survey of the gallery's activities in the Far East will be found in Mr. Bishop's confidential letters, copies of which are transmitted herewith (Appendix B not printed).

As in past years, we have steadfastly adhered to our fundamental practice of conducting our expedition with due respect both for the dignity of the Institution and for the sensibilities of the Chinese, since it is our purpose, as long as we stay in the field, to serve our own immediate ends only to the extent that in so doing we serve also the ends of future archeological research in China and help to establish an atmosphere of greater mutual regard and confidence between native and foreign scientists. The fact that under existing conditions, difficult at times to the point of discouragement, we should have been able to carry out important excavations in southwestern Shansi during the autumn and spring seasons of last year, speaks well, I think for our policy, our field staff, and our Chinese collaborators. Mr. Bishop's detailed illustrated report on these excavations is expected shortly.

PERSONNEL

Archibald G. Wenley returned to the gallery January 5, 1931, after seven years spent abroad in sinological study. Three years were spent in China, two in Europe, and two in Japan.

Miss Grace L. McKenney resigned May 15 because of ill health and returned to her home in Massachusetts.

Mrs. Rita W. Edwards returned May 16, after an absence of 11 months, and resumed her position as secretary to the curator.

Miss Eleanor Thompson, who filled this position during Mrs. Edwards's absence, has transferred to the position vacated by Miss McKenney, in charge of the print section.

William Acker, student assistant, left June 18, 1931, for Holland to resume his sinological studies at the University of Leyden.

Miss Grace Aasen, library assistant, was married on June 20, 1931, to Marvin Lamar Parler.

Herbert E. Thompson worked at the gallery during the weeks of October 26, 1930, February 22, and March 29, 1931.

Y. Kinoshita worked at the gallery from January 24 to July 11, 1931.

Respectfully submitted.

J. E. Lodge, *Curator.*

Dr. C. G. Abbot,

Secretary of the Smithsonian Institution.

APPENDIX 4

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

Sir: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1931, conducted in accordance with the act of Congress approved April 19, 1930. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, $70,280.

M. W. Stirling, chief, left Washington during the latter part of January to continue his archeological researches in Florida. On the way south he took the opportunity to investigate a number of archeological sites in several of the Southern States, notably a group of mounds which had been reported in the vicinity of High Point, N. C., and two mound sites on Pine Island in the Tennessee River in northern Alabama.

A few days were spent in the vicinity of Montgomery, Ala., examining the early historic sites being investigated there by the Alabama Anthropological Society. A large mound had been reported in the vicinity of Flomaton, Ala.; this was visited and found to be a natural formation.

Continuing down the west coast of Florida, Mr. Stirling visited briefly the archeological sites at Crystal River, Safety Harbor, and Alligator Creek. The principal work for the season was commenced on February 5 on Blue Hill Island south of Key Marco, one of the northernmost of the Ten Thousand Island Group. A large sand burial mound was excavated and found to be of early post-Columbian Calusa origin. Excavation of the mound disclosed a number of interesting structural features quite unusual in Florida sand mounds. Six feet above the base of the mound a clay floor was encountered which gave evidence of having been the base of a temple structure, as it was surrounded by post holes and in some instances by the decayed remains of the wooden uprights still in place. This structure had evidently been destroyed and the mound subsequently enlarged by adding 6 feet more of sand above the original substructure. Numerous burials were encountered both above and below the

clay floor. A few articles of European manufacture were recovered from the upper level of the mound. As none were recovered from beneath the temple floor, it is possible that the older section of the mound is of pre-Columbian age. Cultural material recovered was interesting though not abundant. This included characteristic pottery specimens, pendants and ornaments made from fossil shark teeth, shell dishes, cups, celts, and a few stone knives and arrowheads. Articles of European manufacture consisted of glass beads and iron axes of Spanish type. More than 250 burials were removed.

Following the completion of this work, Mr. Stirling went to the island of Haiti where, in the company of H. W. Krieger, of the United States National Museum, he investigated archeological sites previously worked by Mr. Krieger in various parts of the island. Returning from Haiti to Florida, work was continued in the eastern part of the State, where a number of mounds were investigated between Miami and Cape Canaveral.

The most interesting discovery of the entire season consisted in locating two series of large geometric earthworks on the eastern side of the Everglades, not far from Indiantown. One of these groups is one of the largest and best preserved works of this type now existing on the North American continent. It is hoped that at an early date the bureau will be able to begin excavations on this most interesting site. At the completion of this reconnaissance, Mr. Stirling returned to Washington, leaving almost immediately for Chicago in order to attend a meeting of the National Research Council, the purpose of which was to organize research on the subject of early man in America.

Dr. John R. Swanton, ethnologist, was engaged in field work in Louisiana from July 1 to August 14, 1930. It was found that Rosa Pierrette, the sole Indian acquainted with the Ofo language and the one from whom, in 1908, he obtained the only specimens of that language in existence, was dead, and the language therefore is dead also. A search was made for speakers of Atakapa, but all appeared to be gone except one old woman who could barely recall a few words. The Chitimacha Indians of Charenton were visited and a small amount of linguistic material was obtained from them. Of the Tunica at Marksville, only two or three are still able to use the old tongue, but one of these proved to be an ideal informant and Doctor Swanton obtained from him a number of short stories and one long story in native text. The rest of the time was spent at Kinder, where a considerable body of material in Koasati was obtained.

In view of the extinction of Atakapa as a spoken language, Doctor Swanton considered that the words, phrases, and texts collected by Dr. A. S. Gatschet in 1886, which comprise by far the greater portion

of the material in that tongue still preserved, should be published without delay and the greater part of the winter of 1930–31 was spent in editing it. To Gatschet's material have been added the Eastern Atakapa words collected by Murray and the Akokisa vocabulary obtained by the French captain, Bérenger, and published by Du Terrage and Rivet. A bulletin containing all this is now in the hands of the printer.

Work has progressed on the tribal map of North America which is being copied by Mrs. E. C. M. Payne, and additions have been made to the text to accompany it.

Doctor Swanton is preparing the first draft of a Handbook of the Indians of the Southeast.

The closing weeks of the year were devoted to reading the proof of Bulletin 103, entitled "Source Material for the Social and Ceremonial Life of the Choctaw Indians."

Dr. Truman Michelson, ethnologist, was at work among the Kickapoo of Oklahoma at the beginning of the fiscal year. A really representative body of Kickapoo mythology is now available, and it is quite certain that it is more northern than Fox mythology. The ritualistic origin myths are still terra incognita. A good beginning has been made on Kickapoo social organization. In the middle of July Doctor Michelson went among the Foxes of Iowa. The object of the trip was to restore one Fox test phonetically and to obtain some new texts, in the current syllabic script, on Fox ceremonials, in both of which projects he was successful. Doctor Michelson returned to Washington August 4. He completed his memoir on the Fox WâpAnōwiweni and transmitted it for publication February 7. His paper, Contributions to Fox Ethnology, II, Bulletin 95 of the bureau, appeared in the course of the fiscal year.

The remainder of the time was largely taken up studying materials gathered previously and also in extracting from Petter's Cheyenne Dictionary such stems and words as can be rigorously proved to be Algonquian. The material on the physical anthropology of the Cheyenne showed clearly the great variation that occurs among living races. A proper technique was worked out for determining the Cheyenne words of Algonquian origin. Though Petter's alphabet is inadequate, it was possible to partially control this material by comparing it with that of Doctor Michelson. Approximately 700 of such words and stems were extracted. Though the technique mentioned above is very slow, Doctor Michelson is convinced that it is the correct procedure. It was entirely feasible to establish about 70 phonetic shifts which have transformed Cheyenne from normal Algonquian into divergent Algonquian.

Toward the close of May Doctor Michelson left for Oklahoma and renewed his work with the Cheyenne of that State. He restored

phonetically the material extracted from Petter, with the result that it is now possible to formulate the transforming phonetic shifts with greater nicety. He also measured a number of Cheyenne. Though the number is not yet large enough to be absolutely decisive in a statistical sense, there is good reason to believe that the vault of their skulls is low, thus resembling the Dakota Sioux rather than most Algonquian tribes. Some new data on Cheyenne social life and mythology were obtained. It was his privilege to consult with some other anthropologists in Oklahoma and to visit one museum.

John P. Harrington, ethnologist, was engaged during the summer of 1930 in the preparation of his report on the Indians who were brought together at San Juan Bautista Mission in the first half of the nineteenth century by the Spanish-speaking padres from various parts of San Benito County, Calif., and the adjacent region. A valuable vocabulary of the language, recorded by Father Felipe Arroyo de la Cuesta, had already been published by the Smithsonian Institution in the sixties of the last century, but aside from this vocabulary there was little or nothing in print on these Indians. Elaborating a wealth of material obtained from Mrs. Ascención Solórsano, the last San Juan Indian who spoke the language, who died in January, 1930, Mr. Harrington prepared a report on all phases of the life of these Indians, as far as reconstructable. This report tells of the remarkable way in which the language and partial ethnography were rescued from this sole survivor, and then proceeds to the history, geography, and customs of the tribe, including all that could be learned of former religion, ceremony, and mythology.

Mrs. Solórsano was an Indian herb doctor, and a feature of the work during the summer of 1929 had been to obtain specimens and information to cover the ethnobotany of the tribe. Further specimens were obtained in the summer of 1930 by Mrs. Dionisia Mondragón and Miss Marta J. Herrera, daughter and granddaughter of Mrs. Solórsano, and these were all identified by C. V. Morton, of the National Herbarium. This section gives the treatment for curing some 60 different ailments with these herbs and by other curious means. It forms a nucleus for making comparative studies in Indian medicine.

At the end of January, 1931, Mr. Harrington left for California for the purpose of continuing his studies in this region, this time specializing on the Esselen and Antoniano Indians in the southern part of Monterey County. Taking the specimens of San Juan Bautista plants with him and arriving in wild-flower season, a thorough collecting of plants was rewarded with a great mass of information which further elucidated much of the San Juan plant material. This collecting was done in several places in southern Monterey County and simultaneously in San Benito County. Seeds

used for food were actually made up into the food product to get the primitive process, and the same method was followed in the study of medicines.

Along with the plants the field of ethnozoology was thoroughly covered and practically all the animals known to these Indians were identified. Specimens were obtained, especially of birds, which proved to be the most difficult field for identification in the collecting of animal names, and the skins were identified by the division of birds of the National Museum. Eight different kinds of snakes were known by name and identified.

One of the rarest features of the work was the obtaining of a number of old Indian place names in the old Esselen country, the western tributary of the Salinas River known as the Arroyo Seco. A study of the place names resulted in the discovery that the Esselen were not a coastal but an inland people, inhabiting the Arroyo Seco and a section of the Salinas River and centered about Soledad Mission. They were one of the smallest tribes in California, and the name properly begins with an h; they were known in the San Juan Bautista from all that section of California. The expedition went from Monterey to the Aguage de Martin and from there climbed the mountain. Some 40 exposures were made of the various rocks connected with the ceremonies and the springs and camps, and several hundred pages of notes were taken down in California Spanish from Don Angel and others dealing with the history of these ceremonies and the life of Mariana and Joaquin Murrieta. On the way back to the coast the Cruz Cervantes ranch was visited, where Murrietta and Mariana were equipped by Don Cruz for starting their war against the Americans.

An examination of place names and village sites and linguistic studies occupied Mr. Harrington up to the end of June. Not only were vocabularies of early recording utilized but the invaluable records contained in the old mission books were, through the courtesy of Bishop McGinley, of Fresno, placed at the disposal of the Smithsonian Institution for copying, and a considerable part of these books has already been copied and revised with the aid of the oldest Indians.

Dr. F. H. H. Roberts, jr., archeologist, devoted the fiscal year to a number of activities. During the months of July, August, and September, excavations at a site on the Zuñi reservation, 16 miles northeast of the Indian village of Zuñi, were brought to a conclusion. The work had been started the latter part of May, 1930. At the end of the season's field work the ruins of two houses, one containing 64 rooms, the other 20 rooms, and a number of ceremonial chambers

had been cleared of the débris which had accumulated in them in the centuries which have passed since their abandonment.

Evidence showed that the largest of the houses had not been erected as a complete unit and that it was not occupied in its entirety at any time. The central block, together with a superceremonial chamber placed at its southern side, constituted the original block of the structure. Subsequent additions consisted of an east-and-west wing and a series of chambers south of the original portion and east of the great ceremonial chamber. Masonry in the walls of the latter portions was inferior to that in the original section. The outlines of the rooms in these same portions of the building were so irregular that they appeared to have been built by a different group of people. The walls in the original section were constructed in a style characteristic of the ruins in the Chaco Canyon, 85 miles northeast from the Zuñi region. The stonework in the latter portions of the building was suggestive of the type found in the ruins of the Upper Gila area to the south.

The small house did not give evidence of growth stages as distinct as those observed in the large building; it did show, however, that a fairly small structure had been added to on various occasions. The walls in this building were of the same nature as those in the later portions of the larger dwelling, except that the stones were more carefully dressed. This suggested that the small house may have been built by the same group which erected the later portions of the large one.

In addition to the two houses and seven small ceremonial chambers two great kivas were found. Only one of these was excavated. In the case of the other it was possible merely to trace the outer walls in order to obtain the size and position of the structure. The finding of these two great kivas was significant because investigations in the Southwest have shown that such structures are always associated with some form of the Chaco culture. The great kiva connected with the larger of the two dwellings revealed one of the essential characteristics of such structures when the débris which filled it was removed. It had an average diameter of 55 feet. The second of these large circular houses was completely detached from the other buildings in the village and had been placed in a court formed by the other structures. It averaged 78 feet in diameter, which makes it the largest yet discovered.

The excavations yielded 400 specimens of the people's handicraft in addition to the information on house types. Included in the collection are pottery vessels, tools or implements of stone and bone, ornaments, and a number of stone images. The pottery is characterized by examples typical of the Chaco Canyon wares and also speci-

mens characteristic of the Upper Gila region to the south. The summer's investigations demonstrate that the village on the Zuñi Reservation belongs to the great period of the prehistoric pueblos, that designated as Pueblo III in southwestern chronology. The evidence obtained also indicates that there was a fusion of two groups of people at this location: One, the first to arrive, came from the Chaco area in the north, and the other from the Upper Gila villages in the south. Charred timbers obtained from the ruins enabled Dr. A. E. Douglass, of the University of Arizona, to give the dates 1000 to 1030 A. D. for the life of the community.

Upon the completion of the above work one week was spent in making an archeological survey on the Zuñi reservation and in the region west and northwest from that district. As a result of the reconnaissance, a promising site for further investigations was found. Following this, a trip was made to Cortez, Colo., for the purpose of inspecting ruins being excavated by Lee Dawson near the opening into McElmo Canyon, 4 miles southwest from Cortez. It was found that Mr. Dawson had an unusually interesting group of unit-type houses on his property. Of particular interest were the kivas or ceremonial chambers associated with these structures. In many of them the walls had been ornamented with a series of paintings placed in bands encircling the walls. From Cortez the writer went to Denver and from there returned to Washington the middle of October.

During the winter months, galley, page, and final proofs were read on Bulletin 100, a report on work conducted during the summer of 1929, entitled "The Ruins of Kiatuthlanna, Eastern Arizona." In addition, the specimens brought in from the summer field work were studied. Drawings and photographs were made of them for use in a report on the work. Six hundred pages of manuscript, entitled "The Village of the Great Kivas on the Zuñi Reservation, New Mexico," was prepared. Thirty text figures were drawn to accompany this manuscript.

Doctor Roberts left Washington May 14, 1931, for Denver, Colo., for the purpose of inspecting and studying the specimens obtained by the Smithsonian Institution-University of Denver Cooperative Expedition in the summer of 1930 and also for the purpose of examining collections in the Colorado State Museum. He left Denver on May 25 for Santa Fe, N. Mex. At the latter place two days were spent in studying the collections at the Laboratory of Anthropology and at the Museum of New Mexico. From Santa Fe he proceeded to Gallup, N. Mex., where supplies were obtained for a field camp. From Gallup this material was taken to a site 3½ miles south of Allantown, Ariz., where a camp was established and excavations

started on the remains of a large pit-house village. One refuse mound containing 12 burials with accompanying mortuary offerings and two pit houses had been investigated at the close of the fiscal year.

The pit houses were found to be characteristic of that type and quite comparable to those excavated in the Chaco Canyon in 1927, reported in Bulletin 92 of the Bureau of American Ethnology, and to those excavated in eastern Arizona in the summer of 1929, described in Bulletin 100 of the bureau.

From July 1, 1930, to May 10, 1931, J. N. B. Hewitt, ethnologist, was engaged in routine office work, and from the latter date to the end of the fiscal year he was engaged in field service on the Grant of the Six Nations on the Grand River in Ontario, Canada, and, briefly, on the Tuscarora reservation in western New York State.

Mr. Hewitt devoted much time and study to rearranging and retyping some of his native Iroquoian texts which critical revisions and additional data had made necessary to facilitate interlinear translations and to render such texts as legible as possible for the printer.

The texts so treated are the Cayuga version of the founding of the League of the Iroquois as dictated by the late Chief Abram Charles; the version of the Eulogy of the Founders as dictated by Chief Jacob Hess in Cayuga, and also his versions of the addresses introducing the several chants; also, four of the myths of the Wind and Vegetable Gods which are usually represented by wooden faces and husk faces (which are customarily misnamed masks, although their chief purpose is to represent, not to mask). The Onondaga texts of these myths were in great need of careful revision, for their relator was extremely careless in his use of the persons and the tenses of the verbs, frequently changing from the third to the second person and from past to future time by unconsciously employing the language of the rites peculiar to the faces; and also the decipherment of a set of pictographs or mnemonic figures, designed and employed by the late Chief Abram Charles, of the Grand River Reservation in Canada, to recall to his mind the official names and their order of the 49 federal chiefs of the Council of the League of the Iroquois, in chanting the Eulogy of the Founders of the League; and also to recall the 15 sections or burdens of the great Requickening Address of the Council of Condolence and Installation; this paper with illustrations is nearly ready for the printer; and also a critical study of the matter of the Onondaga and the Cayuga texts, giving the several variant versions of the events attending the birth and childhood and work of Deganawida. He was born of a virgin mother, which indicated that underlying them there appeared to be an ideal figure,

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although of course unexpressed. This discovery showed the need for thorough search in the field for a living tradition in which this ideal is fully expressed. Further search was deferred to field work. It was clear that such an ideal enhanced the beauty of the birth story of Deganawida and made more interesting the historicity of such a person. Mr. Hewitt had the great satisfaction of recovering such a tradition in his subsequent field researches. He found that the inferiority complex had precluded his present informants from expressing themselves during the lifetime of other informants, whose recent deaths opened their mouths without the fear of contradiction. The death of Abram Charles within the year made these shy informants vocal.

In January Matthew W. Stirling, chief of the Bureau of American Ethnology, requested Mr. Hewitt to undertake the editing of the Manuscript Journal of Rudolph Friederich Kurz, of Berne, Switzerland, in the manner in which he had prepared the Edwin Thompson Denig Report on the Indian Tribes of the Upper Missouri River, published in the Forty-sixth Annual Report of the Bureau of American Ethnology. The Kurz manuscript was written in German during the years 1846 to 1852. The typed German text consists of 454 pages of large legal cap size, while the English translation of it by Myrtis Jarrell occupies 780 pages. The journal is a narrative of Mr. Kurz's experiences in a trip up the Mississippi River from New Orleans to St. Louis, thence up the Missouri to Fort Union at the Mouth of the Yellowstone River, and of his difficulties with the Indians while endeavoring to make drawings or pictures of them. There are 125 pen sketches of Indians and others accompanying the manuscript.

Mr. Hewitt represents the Bureau of American Ethnology, Smithsonian Institution, on the United States Geographic Board, and is a member of its executive committee. In connection with the forthcoming issue of the sixth report of this board much extra work had to be done by members of the executive committee. Mr. Hewitt prepared a memorandum for a portion of the introduction. Mr. Hewitt also devoted much time and study to the collection and preparation of data for official replies to correspondents of the bureau, some demanding long research. Miss Mae W. Tucker has assisted Mr. Hewitt in the care of the manuscript and phonograph and photograph records of the archives.

On May 10, 1931, Mr. Hewitt left Washington, D. C., on field duty and returned to the bureau July 2, 1931. During this trip he visited the Grand River grant of the Six Nations of Iroquois Indians dwelling near Brantford, Canada, and also the Tuscarora Reservation near Niagara Falls, N. Y.

Winslow M. Walker was appointed to the staff of the Bureau of American Ethnology as associate anthropologist in March, 1931. He resumed his research in Hawaiian archeology, begun during a year's stay in the Hawaiian Islands in 1929, in preparation for a paper on Hawaiian sculpture.

In preparation for work in the field Mr. Walker undertook research in the early narratives of exploration in Louisiana and Arkansas. He left Washington May 29 to investigate some caves in the vicinity of Gilbert, Ark., in the Ozark Mountains, with the hope of being able to throw new light on the Ozark bluff dwellers and other early inhabitants of the caves. Sixteen caves were explored and excavations were made in several of the most promising. A large cave at Cedar Grove yielded several skeletons and a considerable number of stone, flint, and bone artifacts. As the fiscal year closed Mr. Walker was still engaged in excavating this cavern. He intends to make a brief survey of certain mounds and village sites along the Red River Valley in the northern part of Louisiana on the completion of his work in Arkansas.

SPECIAL RESEARCHES

The study of Indian music for the Bureau of American Ethnology has been carried forward during the past year by Miss Frances Densmore. The three phases of this research are (1) the recording of songs and collecting of other material in the field, including the purchase of specimens; (2) the transcription and analysis of songs, with the development of information; and (3) the preparation of material for publication. All these phases have received attention during the year, and the songs of three hitherto unstudied localities have been recorded.

Early in July, 1930, Miss Densmore went to Grand Portage, an isolated Chippewa village on Lake Superior, near the Canadian boundary. This village was visited in 1905, a ceremony was witnessed, and one of its songs written down; therefore a return to Grand Portage was particularly interesting. The purpose of the trip was to witness the Chippewa dances on the Fourth of July, but she remained more than three weeks, continuing her study of native customs. Several songs of the *wabunowin* were heard and translated, these resembling the songs of the Grand Medicine, which formed a subject of intensive study during 1907–1911. She also witnessed the tipi-shaking of an Indian medicine man and listened to his songs for almost an hour. This performance is very rare at the present time. Although the evening was quiet, the tipi was seen to sway as though buffeted by a tempest, then remain motionless a few seconds and again shake convulsively. This was continuous while Miss Densmore watched the performance and was said to have continued

several hours afterwards. Inside the tipi sat the medicine man, believed to be talking with spirits whom he had summoned, the spirits making known their presence by the shaking of the conical structure. The next day the medicine man said that he had summoned the spirits in order to ascertain whether his treatment of a certain sick man would be successful. He said that if the spirits "spoke loud and clear" the man would recover, but if their voices were faint the man would die. The response was said to have been satisfactory, and accordingly he instituted a "beneficial dance," which was attended by Miss Densmore, and the songs heard for a considerable time. These, like the songs in the tipi, resembled the songs of the Chippewa Grand Medicine Society.

The study of Indian music was continued by a trip to Kilbourn, Wis., during August and September. Two pageants are given simultaneously at The Dalles of the Wisconsin River, near Kilbourn, each employing about 100 Indians. In the pageants the swan and hoop dance, as well as war and social dances of the Winnebago, were seen. The dances of other tribes presented in the pageants included the eagle dance and other pueblo dances. Songs of the swan, hoop, and frog dances were later recorded by leading pageant singers.

At Kilbourn Miss Densmore recorded numerous songs of Pueblo Indians from Isleta and Cochiti, these consisting chiefly of corn-grinding and war songs. The words of these songs are highly poetic and many of the melodies resemble Acoma songs in structure.

As John Bearskin and his family were traveling from Kilbourn to their home in Nebraska they passed through Red Wing, Minn., and songs were recorded at Miss Densmore's home. Bearskin recorded three complete sets of the Winnebago medicine lodge songs and a set of Buffalo feast songs.

In January, 1931, Miss Densmore went to Washington, where she worked on the preparation of material for publication, and proceeded thence to Miami, Fla., where she began a study of Seminole music, recording songs of the corn dance from the man who leads the singing in that ceremony; also the songs that precede a hunting expedition. The customs of the Seminole were studied and a collection of specimens was obtained. This collection includes two complete costumes and is now the property of the United States National Museum.

The second phase of the research is represented by eight manuscripts which include the transcriptions and analyses of 77 songs and two flute melodies recorded by Winnebago, Isleta, Cochiti, and Seminole Indians. The cumulative analyses of Indian songs has been continued and now comprises 1,553 songs. The 14 tables submitted during this year constitute a comparison between a large series of Nootka and Quileute songs and the songs previously analyzed by the same method.

The third phase of work comprised the preparation for publication of "Menominee Music" and "Acoma Music."

Frank M. Setzler, assistant curator, division of archeology, United States National Museum, was detailed to the bureau for the purpose of conducting an archeological investigation in Texas. After briefly examining several sites at Victoria and Brownsville along the Gulf coast, he excavated four caves and one rock shelter on the Mollie B. Knight ranch, in Presidio County, and visited several other caverns in the vicinity.

From one large cave a total of 70 specimens, including baskets, matting, cradles, sandals, beads, corn, gourd shards, and one skeleton, were recovered. No pottery or evidence of European influence was found. Although the site is only 150 miles east of a marginal Basket Maker culture, no local trace was found of these early southwestern people. The material differs in some respects from any other in the Museum and more research will be required before it can be definitely identified.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the bureau was continued through the year by Stanley Searles, editor, assisted by Mrs. Frances S. Nichols, editorial assistant. The status of the publications is presented in the following summary:

PUBLICATIONS ISSUED

Forty-fifth Annual Report. Accompanying papers: The Salishan Tribes of the Western Plateaus (Teit, edited by Boas); Tattooing and Face and Body Painting of the Thompson Indians, British Columbia (Teit, edited by Boas); The Ethnobotany of the Thompson Indians of British Columbia (Steedman); The Osage Tribe; Rite of the Wa-xo-be (LaFlesche). vii+857 pp., 29 pls., 47 figs.

Forty-sixth Annual Report. Accompanying papers; Anthropological Survey in Alaska (Hrdlička); Report to the Honorable Isaac S. Stevens, Governor of Washington Territory, on the Indian Tribes of the Upper Missouri (Denig, edited by Hewitt). vii+654 pp., 80 pls., 35 figs.

Bulletin 96. Early Pueblo Ruins in the Piedra District, Southwestern Colorado (Roberts). ix+190 pp., 55 pls., 40 figs.

Bulletin 97. The Kamia of Imperial Valley (Gifford). vii+94 pp., 2 pls., 4 figs.

Bulletin 100. The Ruins at Kiatuthlanna, Eastern Arizona (Roberts). viii+195 pp., 47 pls., 31 figs.

PUBLICATIONS IN PRESS

Forty-seventh Annual Report. Accompanying papers: The Acoma Indians (White); Isleta, New Mexico (Parsons); Introduction to Zuñi Ceremonialism, and Zuñi Origin Myths (Bunzel); Zuñi Ritual Poetry (Bunzel); Zuñi Katcinas (Bunzel).

Bulletin 94. Tobacco Among the Karuk Indians of California (Harrington).

Bulletin 98. Tales of the Cochiti Indians (Benedict).

Bulletin 99. Cherokee Sacred Formulas and Medicinal Prescriptions (Mooney and Olbrechts).

Bulletin 101. Indian Blankets of the North Pacific Coast (Kissell).

Bulletin 102. Menominee Music (Densmore).

Bulletin 103. Source Material for the Social and Ceremonial Life of the Choctaw Indians (Swanton).

Bulletin 104. A Survey of the Ruins in the Region of Flagstaff, Arizona (Colton).

Bulletin 105. Notes on the Wâpʌnōwiweni (Michelson).

DISTRIBUTION OF PUBLICATIONS

The distribution of the publications of the bureau has been continued under the charge of Miss Helen Munroe, assisted by Miss Emma B. Powers. Publications distributed were as follows:

Report volumes and separates	6,003
Bulletins and separates	13,924
Contributions to North American Ethnology	33
Miscellaneous publications	515
Total	20,475

As compared with the fiscal year ending June 30, 1930, there was a decrease of 4,393. This decrease is mainly in the distribution of bulletins and separates, and possibly is largely explained by the very large number of separates from the handbook which were sent in the previous year to the many groups of Camp Fire Girls. No great demand from any one group was received in this past fiscal year.

Twenty-eight addresses were added to the mailing list during the year and 20 were taken off. The mailing list now stands at 1,635, in addition to the members of the staff of the bureau and other branches of the Institution who receive the publications regularly as issued.

ILLUSTRATIONS

Following is a summary of work accomplished in the illustration branch of the bureau under the supervision of De Lancey Gill, illustrator:

Photographs and drawings retouched, lettered, and otherwise made ready for engraving	748
Drawings made, including maps, diagrams, etc	48
Engravers' proofs criticized	524
Printed editions of colored plates examined at Government Printing Office	7,000
Correspondence attended to (letters)	135
Photographs selected and catalogued for private publication	310
Photo-laboratory work by Dr. A. J. Olmsted, National Museum, in cooperation with the Bureau of American Ethnology:	
Negatives	154
Prints	335
Lantern slides	91
Films developed from field exposures	48

During the early part of the calendar year Miss Mae W. Tucker was detailed to this branch to assist in listing and cataloguing the great collection of Indian negatives already classified by Mr. Gill in previous years. Of the purely ethnologic subjects, including portraits, arts, and industries, the list will embrace more than 7,000 units. This work, so long delayed, has progressed most satisfactorily.

LIBRARY

The reference library has continued under the care of Miss Ella Leary, librarian, assisted by Thomas Blackwell.

During the year 600 volumes were accessioned, of which 97 were acquired by purchase, 100 by binding of periodicals, and 403 by gift and exchange; also 190 pamphlets and 3,500 serials, chiefly the publications of learned societies, were received and recorded, of which 28 were obtained by purchase, the remainder being received through exchange, giving us at the close of the year a working library of 26,671 volumes, 16,717 pamphlets, and several thousand unbound periodicals. Books loaned during the year numbered 975 volumes. During the year 473 volumes were bound. In addition to the use of its own library, which is becoming more valuable through exchange and by limited purchase, it was found necessary to draw on the Library of Congress for the loan of about 250 volumes, and in turn the bureau library was frequently consulted by officers of other Government establishments, as well as by students not connected with the Smithsonian Institution. The purchase of books and periodicals has been restricted to such as relate to the bureau's researches. During the year the cataloguing has been carried on as new accessions were acquired and good progress was made in cataloguing ethnologic and related articles in the earlier serials. The catalogue was increased by the addition of 3,500 cards. A considerable amount of reference work was done in the usual course of the library's service to investigators and students, both in the Smithsonian Institution and outside.

COLLECTIONS

Accession No.

111046. Human skeletal material from a gravel bed along the Patuxent River, Md., collected by T. Dale Stewart on June 16, 1930. (12 specimens.)

111697. About 100 crania and parts of skeletons from Safety Harbor, Fla., collected by M. W. Stirling. (139 specimens.)

111961. Miniature clay toys made by Navajo Indian children and collected by Dr. W. H. Spinks at Chin Lee, Ariz., and 15 snapshots. (37 specimens.)

112277. Collection of 802 ivory specimens, etc., secured by Dr. A. Hrdlička along the Kuskokwim in 1930 from funds supplied by the bureau. (802 specimens.)

112393. Archeological and skeletal material collected by Dr. F. H. H. Roberts, jr., during the summer of 1929 from a site in Arizona. (553 specimens.)

Accession No.

112888. Archeological material from the vicinity of Tampa Bay, Fla., collected by M. W. Stirling in 1930. (115 specimens.)

114648. Skeletal material from Horrs Island, Collier County, Fla., collected during February and March, 1931, by M. W. Stirling. (150 specimens.)

PROPERTY

Office equipment was purchased to the amount of $571.25.

MISCELLANEOUS

The correspondence and other clerical work of the office has been conducted by Miss May S. Clark, clerk to the chief, assisted by Anthony W. Wilding, clerk. Miss Mae W. Tucker, stenographer, was engaged in copying manuscript material for Doctor Swanton and in assisting Mr. Hewitt in his work as custodian of manuscripts and phonograph records. The manuscript Dictionary of * * * Indian Languages of North, Central, and South America and the West Indies, compiled by W. R. Gerard, which was in danger of becoming illegible due to the frayed condition of the paper on which it was written and the faded writing, has been copied by Miss Tucker. Work was begun on the catalogue of the photographic negatives belonging to the bureau. To date approximately 7,000 negatives have been listed.

During the course of the year information was furnished by members of the staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods to the south. Various specimens sent to the bureau were identified and data on them furnished for their owners.

Personnel.—Winslow M. Walker was appointed as associate anthropologist on the staff of the bureau on March 6, 1931, and Dr. William D. Strong as ethnologist on July 1, 1931.

Miss May S. Clark, clerk, retired June 30, 1931.

Respectfully submitted.

M. W. STIRLING, *Chief.*

Dr. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1931:

The appropriation granted by Congress for the support of the system of international exchanges during the year was $52,810, an increase of $1,513 over the amount allowed for the preceding year. Of this increase, $1,000 was for freight, $160 to cover the additional sum required to meet the provisions of the Brookhart Act amending section 13 of the classification act of 1923, and $353 to advance to the next step in their respective grades those of the employees of the exchange office eligible for promotion. The repayments from departmental and other establishments aggregated $5,000.57, making the total available resources for conducting the service during 1931 $57,810.57.

The total number of packages handled was 641,338, a decrease from the previous year of 53,327 (7.7 per cent). The weight of these packages was 642,190 pounds, a falling off of 65,904 pounds (9.3 per cent). These decreases no doubt were due to the world-wide depression. However, the economic condition affected the output of literature more abroad than in the United States, as will be noted when it is stated that the number of packages sent through the International Exchange Service decreased only 6 per cent, while those received from abroad decreased nearly 22 per cent.

The publications passing through the service are classified as parliamentary documents, departmental documents, and miscellaneous scientific and literary publications. The number and weight of the packages containing the publications coming under these different headings are as follows:

	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad	261, 155		114, 619	
Publications received in return for parliamentary documents		10, 331		29, 196
United States departmental documents sent abroad	191, 266		155, 089	
Publications received in return for departmental documents		8, 020		24, 076
Miscellaneous scientific and literary publications sent abroad	132, 737		229, 280	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States		37, 829		89, 930
Total	585, 158	56, 180	498, 988	143, 202
Grand total	641, 338		642, 190	

During the year 3,002 boxes were shipped abroad, a decrease from the number for the preceding 12 months of 233, a little over 7 per cent. Of the total number of boxes, 692 contained full sets of United States official documents for authorized depositories abroad, and the remainder (2,310) were filled with publications for miscellaneous correspondents. The boxes measured 16,003 cubic feet.

The number of boxes sent to each country is given in the following table:

Consignments of exchanges forwarded to foreign countries

Country	Number of boxes	Country	Number of boxes
Albania	10	Latvia	22
Argentina	65	Lithuania	2
Austria	50	Mexico	11
Belgium	73	Netherlands	88
Brazil	55	New South Wales	48
British Colonies	13	New Zealand	31
Bulgaria	3	Norway	46
Canada	44	Palestine	48
Chile	38	Persia	2
China	89	Peru	27
Colombia	25	Poland	69
Costa Rica	23	Portugal	24
Cuba	11	Queensland	25
Czechoslovakia	67	Rumania	24
Danzig	1	Russia	165
Denmark	55	South Australia	26
Egypt	20	Spain	38
Estonia	22	Sweden	95
Finland	19	Switzerland	84
France	183	Tasmania	21
Germany	383	Turkey	10
Great Britain and Ireland	236	Ukraine	61
Greece	2	Union of South Africa	58
Guatemala	2	Uruguay	24
Haiti	3	Venezuela	33
Hungary	40	Victoria	46
India	77	Western Australia	20
Italy	119	Yugoslavia	19
Japan	106		
Korea	1	Total	3,002

As explained in previous reports, in addition to the packages forwarded abroad in boxes for distribution by foreign exchange bureaus, many are transmitted direct to their destinations by mail—some because it is more economical to send by mail than by freight; some, like the daily issue of the Congressional Record, because treaty stipulations provide that they shall be so forwarded; and some for the reason that they are for places remote from existing exchange agencies. The total number of packages transmitted by mail during the year was 76,609, an increase over last year of 8,664.

Last year mention was made that nine boxes of exchanges from Germany were destroyed at the steamship pier in New York through the burning and sinking of the vessel on board of which the boxes were being transmitted to this country. I regret to report that during the current fiscal year eight boxes for China met a similar fate at the pier in New York, the steamship *President Harrison*, on board

of which the consignment had been placed for transmission to China, having been destroyed by fire and water.

As usual, assistance was rendered during the year to the Library of Congress in procuring for its division of documents copies of various foreign governmental publications missing in its collections. Aid also was given to a number of establishments, both here and abroad, in obtaining specially desired publications. For this service, as well as for the help in the distribution of exchanges, letters of appreciation are often received by the Institution from its correspondents.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

There are now forwarded to foreign depositories of United States official documents 112 sets—62 full and 50 partial—an increase of three over the number transmitted last year. Afghanistan, Bengal, and the Vatican Library were added to the list of those countries receiving partial sets. Greece, to which the shipment of a full set was temporarily suspended, has been listed to receive a partial set. The partial set sent to Alsace-Lorraine has been discontinued.

The address to which the partial set for Guatemala was forwarded has been changed from the Secretaria de Relaciones Exteriores to the Biblioteca Nacional. The depository in Poland to which a full set of Government documents is forwarded has been changed by the Polish Government from the Library of the Ministry of Foreign Affairs to the National Library in Warsaw.

A complete list of the depositories is given below:

DEPOSITORIES OF FULL SETS

ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.
- BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata, La Plata. (Depository of the Province of Buenos Aires.)

AUSTRALIA: Library of the Commonwealth Parliament, Canberra.
- NEW SOUTH WALES: Public Library of New South Wales, Sydney.
- QUEENSLAND: Parliamentary Library, Brisbane.
- SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
- TASMANIA: Parliamentary Library, Hobart.
- VICTORIA: Public Library of Victoria, Melbourne.
- WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

AUSTRIA: Bundeskanzleramt, Herrengasse 23, Vienna I.

BELGIUM: Bibliothèque Royale, Brussels.

BRAZIL: Bibliotheca Nacional, Rio de Janeiro.

CANADA: Library of Parliament, Ottawa.
- MANITOBA: Provincial Library, Winnipeg.
- ONTARIO: Legislative Library, Toronto.
- QUEBEC: Library of the Legislature of the Province of Quebec.

CHILE: Biblioteca del Congreso Nacional, Santiago.

CHINA: Bureau of International Exchange, Academia Sinica, Shanghai.
COLOMBIA: Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Secretaría de Estado (Asuntos Generales y Canje Internacional), Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Kongelige Bibliotheket, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).
FRANCE: Bibliothèque Nationale, Paris.
PARIS: Préfecture de la Seine.
GERMANY: Reichstauschstelle im Reichsministerium des Innern, Berlin C 2.
BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the State of Baden.)
BAVARIA: Bayerische Staatsbibliothek, Munich.
PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
SAXONY: Sächische Landesbibliothek, Dresden—N. 6.
WURTEMBURG: Landesbibliothek, Stuttgart.
GREAT BRITAIN:
ENGLAND: British Museum, London.
GLASGOW: City Librarian, Mitchell Library, Glasgow.
LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
HUNGARY: Hungarian House of Delegates, Budapest.
INDIA: Imperial Library, Calcutta.
IRISH FREE STATE: National Library of Ireland, Dublin.
ITALY: Ministero dell'Educazione Nazionale, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LATVIA: Bibliothèque d'Etat, Riga.
MEXICO: Biblioteca Nacional, Mexico, D. F.
NETHERLANDS: Royal Library, The Hague.
NEW ZEALAND: General Assembly Library, Wellington.
NORTHERN IRELAND: Ministry of Finance, Belfast.
NORWAY: Universitets-Bibliotek, Oslo. (Depository of the Government of Norway.)
PERU: Biblioteca Nacional, Lima.
POLAND: Bibliothèque Nationale, Warsaw.
PORTUGAL: Biblioteca Nacional, Lisbon.
RUMANIA: Academia Română, Bucharest.
RUSSIA: Shipments temporarily suspended.
SPAIN: Oficina Española de Cambio Internacional, Paseo de Recoletos 20, Madrid.
SWEDEN: Kungliga Biblioteket, Stockholm.
SWITZERLAND:
Bibliothèque Centrale Fédérale, Berne.
Library of the League of Nations, Geneva.
TURKEY: Ministère de l'Instruction Publique, Ankara.
UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
YUGOSLAVIA: Ministère de l'Éducation, Belgrade.

DEPOSITORIES OF PARTIAL SETS

Afghanistan: Ministry of Foreign Affairs, Publications Department, Kabul.

Austria:

Vienna: Magistrat der Stadt Wien, Abteilung 51–Statistik.

Bolivia: Biblioteca del H. Congreso Nacional, La Paz.

Brazil:

Minas Geraes: Directoria Geral de Estatistica em Minas, Bello Horizonte.

Rio de Janeiro: Bibliotheca da Assemblea Legislativa do Estado, Nictheroy.

British Guiana: Government Secretary's Office, Georgetown, Demerara.

Bulgaria: Ministère des Affaires Étrangères, Sofia.

Canada:

Alberta: Provincial Library, Edmonton.

British Columbia: Legislative Library, Victoria.

New Brunswick: Legislative Library, Fredericton.

Nova Scotia: Provincial Secretary of Nova Scotia, Halifax.

Prince Edward Island: Legislative Library, Charlottetown.

Saskatchewan: Government Library, Regina.

Ceylon: Colonial Secretary's Office (Record Department of the Library), Colombo.

China: National Library, Peiping.

Danzig: Stadtbibliothek, Free City of Danzig.

Dominican Republic: Biblioteca del Senado, Santo Domingo.

Ecuador: Biblioteca Nacional, Quito.

Finland: Parliamentary Library, Helsingfors.

Germany:

Bremen: Senatskommission für Reichs- und Auswärtige Angelegenheiten.

Hamburg: Senatskommission für Reichs- und Auswärtige Angelegenheiten.

Hesse: Universitäts-Bibliothek, Giessen.

Lübeck: President of the Senate.

Thuringia: Rothenberg-Bibliothek, Landesuniversität, Jena.

Greece: Library of Parliament, Athens.

Guatemala: Biblioteca Nacional, Guatemala.

Haiti: Secrétaire d'Etat des Relations Extérieures, Port-au-Prince.

Honduras: Biblioteca y Archivo Nacionales, Tegucigalpa.

Iceland: National Library, Reykjavik.

India:

Assam: General and Judicial Department, Shillong.

Bengal: Education Department, Government of Bengal, Darjeeling.

Bihar and Orissa: Revenue Department, Patna.

Bombay: Undersecretary to the Government of Bombay, General Department, Bombay.

Burma: Secretary to the Government of Burma, Education Department, Rangoon.

Central Provinces: General Administration Department, Nagpur.

Madras: Chief Secretary to the Government of Madras, Public Department, Madras.

Punjab: Chief Secretary to the Government of the Punjab, Lahore.

United Provinces of Agra and Oudh: University of Allahabad, Allahabad.

Jamaica: Colonial Secretary, Kingston.

Liberia: Department of State, Monrovia.

Lithuania: Ministère des Affaires Étrangères, Kaunas (Kovno).

Malta: Minister for the Treasury, Valetta.

Newfoundland: Colonial Secretary, St. Johns.
Nicaragua: Superintendente de Archivos Nacionales, Managua.
Panama: Secretaría de Relaciones Exteriores, Panama.
Paraguay: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asunción.
Salvador: Ministerio de Relaciones Exteriores, San Salvador.
Siam: Department of Foreign Affairs, Bangkok.
Straits Settlements: Colonial Secretary, Singapore.
Vatican City: Biblioteca Apostolica Vaticana, Vatican City, Rome, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

The number of copies of the daily issue of the Congressional Record forwarded to foreign legislative bodies and other governmental establishments is 102, the same as last year.

There is given below a complete list of the States taking part in the immediate exchange of the official journal, together with the names of the establishments to which the Record is mailed.

DEPOSITORIES OF CONGRESSIONAL RECORD

Argentina:
- Biblioteca del Congreso Nacional, Buenos Aires.
- Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.
- Buenos Aires: Biblioteca del Senado de la Provincia de Buenos Aires, La Plata.

Australia:
- Library of the Commonwealth Parliament, Canberra.
- New South Wales: Library of Parliament of New South Wales, Sydney.
- Queensland: Chief Secretary's Office, Brisbane.
- Western Australia: Library of Parliament of Western Australia, Perth.

Austria: Bibliothek des Nationalrates, Vienna I.
Belgium: Bibliothèque de la Chambre des Représentants, Brussels.
Bolivia: Biblioteca del H. Congreso Nacional, La Paz.
Brazil:
- Bibliotheca do Congresso Nacional, Rio de Janeiro.
- Amazonas: Archivo, Bibliotheca e Imprensa Publica, Manáos.
- Bahia: Governador do Estado de Bahia, São Salvador.
- Espirito Santo: Presidencia do Estado do Espirito Santo, Victoria.
- Rio Grande do Sul: "A Federação," Porto Alegre.
- Sergipe: Director da Imprensa Official, Aracaju.
- São Paulo: Diario Official do Estado de São Paulo, São Paulo.

British Honduras: Colonial Secretary, Belize.
Canada:
- Library of Parliament, Ottawa.
- Clerk of the Senate, Houses of Parliament, Ottawa.

China: National Library, Pei Haí, Peiping.
Cuba:
- Biblioteca de la Cámara de Representantes, Habana.
- Biblioteca del Senado, Habana.

Czechoslovakia: Bibliothèque de l'Assemblée Nationale, Prague.
Danzig: Stadtbibliothek, Danzig.
Denmark: Rigsdagens Bureau, Copenhagen.
Dominican Republic: Biblioteca del Senado, Santo Domingo.

DUTCH EAST INDIES: Volksraad von Nederlandsch-Indië, Batavia, Java.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).
FRANCE:
- Chambre des Députés, Service de l'Information Parlementaire Étrangère, Paris.
- Bibliothèque du Sénat, au Palais du Luxembourg, Paris.

GERMANY:
- Deutsche Reichstags-Bibliothek, Berlin, N. W. 7.
- ANHALT: Anhaltische Landesbücherei, Dessau.
- BADEN: Universitäts-Bibliothek, Heidelberg.
- BRAUNSCHWEIG: Bibliothek des Braunschweigischen Staatsministeriums, Braunschweig.
- MECKLENBURG-SCHWERIN: Staatsministerium, Schwerin.
- MECKLENBURG-STRELITZ: Finanzdepartment des Staatsministeriums, Neustrelitz.
- OLDENBURG: Oldenburgisches Staatsministerium, Oldenburg i. O.
- PRUSSIA: Bibliothek des Preussischen Landtages, Prinz Albrecht Strasse 5, Berlin, S. W. 11.
- SCHAUMBURG-LIPPE: Schaumburg-Lippische Landesregierung, Bücheburg,

GIBRALTAR: Gibraltar Garrison Library Committee, Gibraltar.
GREAT BRITAIN: Library of the Foreign Office, London.
GREECE: Library of Parliament, Athens.
GUATEMALA: Archivo General del Gobierno, Guatemala.
HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.
HUNGARY: Bibliothek des Abgeordnetenhauses, Budapest.
INDIA: Legislative Department, Simla.
IRAQ: Chamber of Deputies, Bagdad, Iraq (Mesopotamia).
IRISH FREE STATE: Dail Eireann, Dublin.
ITALY:
- Biblioteca della Camera dei Deputati, Rome.
- Biblioteca del Senato del Regno, Rome.
- Ufficio degli Studi Legislativi, Senato del Regno, Rome.

LATVIA: Library of the Saeima, Riga.
LIBERIA: Department of State, Monrovia.
MEXICO: Secretaria de la Cámara de Diputados, Mexico, D. F.
- AGUASCALINTES: Gobernador del Estado de Aguacalientes, Aguascalientes.
- CAMPECHE: Gobernador del Estado de Campeche, Campeche.
- CHIPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.
- CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.
- COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.
- COLIMA: Gobernador del Estado de Colima, Colima.
- DURANGO: Gobernador Constitucional del Estado de Durango, Durango.
- GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.
- GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.
- JALISCO: Biblioteca del Estado, Guadalajara.
- LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali, B. C. Mexico.
- MEXICO: Gaceta del Gobierno, Toluca, Mexico.
- MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.
- MORELOS: Palacio de Gobierno, Cuernavaca.
- NAYARIT: Gobernador de Nayarit, Tepic.
- NUEVO LEON: Biblioteca del Estado, Monterey.

MEXICO—Continued.

OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.

PUEBLA: Secretaría General de Gobierno, Zaragoza.

QUERETARO: Secretaría General de Gobierno, Sección de Archivo, Queretaro.

SAN LUIS POTOSI: Congreso del Estado, San Luois Potosi.

SINALOA: Gobernador del Estado de Sinaloa, Culiacan.

SONORA: Gobernador del Estado de Sonora, Hermosillo.

TABASCO: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.

TAMAULIPAS: Secretaría General de Gobierno, Victoria.

TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.

VERA CRUZ: Gobernador del Estado de Vera Cruz, Departamento de Gobernacíon y Justicia, Jalapa.

YUCATÁN: Gobernador del Estado de Yucatán, Mérida, Yucatán.

NEW ZEALAND: General Assembly Library, Wellington.

NORWAY: Storthingets Bibliothek, Oslo.

PERSIA: Library of the Persian Parliament, Téhéran.

PERU: Cámara de Diputados, Congreso Nacional, Lima.

POLAND: Ministère des Affaires Étrangères, Warsaw.

PORTUGAL: Biblioteca do Congresso da Republica, Lisbon.

RUMANIA:

Bibliothèque de la Chambre des Députés, Bucharest.

Ministère des Affaires Étrangéres, Bucharest.

SPAIN:

Biblioteca del Congreso Nacional, Madrid.

BARCELONA: Biblioteca de la Comisión Permanente Provincial de Barcelona, Barcelona.

SWITZERLAND:

Bibliothèque de l'Assemblée Fédérale Suisse, Berne.

Library of the League of Nations, Geneva.

SYRIA:

Ministère des Finances de la République Libanaise, Service du Matériel, Beirut.

Governor of the State of Alaouites, Lattaquié.

TURKEY: Turkish Grand National Assembly, Ankara.

UNION OF SOUTH AFRICA:

Library of Parliament, Cape Town, Cape of Good Hope.

State Library, Pretoria, Transvaal.

URUGUAY: Biblioteca de la Cámara de Representantes, Montevideo.

VENEZUELA: Cámara de Diputados, Congreso Nacional, Caracas.

FOREIGN EXCHANGE AGENCIES

The Polish Service of International Exchanges has been detached from the Ministry of Foreign Affairs and transferred to the National Library.

The Spanish Office of International Exchange was reorganized in October, 1930, and is now under the Ministry of Public Instruction.

A list of the agencies abroad through which the distribution of exchanges is effected is given below. Most of these agencies for-

ward consignments to the Institution for distribution in the United States.

LIST OF EXCHANGE AGENCIES

ALGERIA, via France.

ANGOLA, via Portugal.

ARGENTINA: Comisión Protectora de Bibliotecas Populares, Calle Córdoba 931, Buenos Aires.

AUSTRIA: Internationale Austauschstelle, Bundeskanzleramt, Herrengasse 23, Vienna I.

AZORES, via Portugal.

BELGIUM: Service Belge des Échanges Internationaux, Rue des Longs-Chariots. 46, Brussels.

BOLIVIA: Oficina Nacional de Estadistica, La Paz.

BRAZIL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.

BRITISH COLONIES: Crown Agents for the Colonies, London.

BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.

BRITISH HONDURAS: Colonial Secretary, Belize.

BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.

CANADA: Sent by mail.

CANARY ISLANDS, via Spain.

CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

CHINA: Bureau of International Exchange, Academia Sinica, 331 Avenue du Roi Albert, Shanghai.

COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA: Sent by mail.

CZECHOSLOVAKIA: Service Tchécoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1–79.

DANZIG: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.

DENMARK: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Copenhagen.

DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.

ECUADOR: Ministerio de Relaciones Exteriores, Quito.

EGYPT: Bureau des Publications, Ministère des Finances, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).

FINLAND: Delegation of the Scientific Societies of Finland, Helsingfors.

FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.

GREAT BRITAIN AND IRELAND: Messrs. Wheldon & Wesley, 2, 3, and 4 Arthur St., New Oxford St., London W. C. 2.

GREECE: Bibliothèque Nationale, Athens.

GREENLAND, via Denmark.

GUATEMALA: Instituto Nacional de Varones, Guatemala.

HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.

HONDURAS: Biblioteca Nacional, Tegucigalpa.

Hungary: Hungarian Libraries Board, Budapest, IV.
Iceland, via Denmark.
India: Superintendent of Stationery, Bombay.
Italy: R. Ufficio degli Scambi Internazionali, Ministero dell'Educazione Nazionale, Rome.
Jamaica: Institute of Jamaica, Kingston.
Japan: Imperial Library of Japan, Tokyo.
Java, via Netherlands.
Korea: Government General, Seoul.
Latvia: Service des Échanges Internationaux, Bibliothèque d'État de Lettonie, Riga.
Liberia: Bureau of Exchanges, Department of State, Monrovia.
Lithuania: Sent by mail.
Lourenço Marquez, via Portugal.
Luxemburg, via Belgium.
Madagascar, via France.
Madeira, via Portugal.
Mexico: Sent by mail.
Mozambique, via Portugal.
Netherlands: International Exchange Bureau of the Netherlands, Royal Library, The Hague.
New South Wales: Public Library of New South Wales, Sydney.
New Zealand: Dominion Museum, Wellington.
Nicaragua: Ministerio de Relaciones Exteriores, Managua.
Norway: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.
Palestine: Hebrew University Library, Jerusalem.
Panama: Sent by mail.
Paraguay: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asunción.
Peru: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
Poland: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.
Portugal: Secção de Trocas Internacionaes, Biblioteca Nacional, Lisbon.
Queensland: Bureau of Exchanges of International Publications, Chief Secretary's Department, Brisbane.
Rumania: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.
Russia: Academy of Sciences, Leningrad.
Salvador: Ministerio de Relaciones Exteriores, San Salvador.
Siam: Department of Foreign Affairs, Bangkok.
South Australia: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.
Spain: Oficina Española de Cambio Internacional, Paseo de Recoletos 20, Madrid.
Sumatra, via Netherlands.
Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.
Switzerland: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.
Syria: American University of Beirut.

TASMANIA: Secretary to the Premier, Hobart.
TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.
TUNIS, via France.
TURKEY: Robert College, Istanbul.
UNION OF SOUTH AFRICA: Government Printing Works, Pretoria, Transvaal.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
YUGOSLAVIA: Ministère des Affaires Étrangères, Belgrade.

Repectfully submitted.

C. W. SHOEMAKER,
Chief Clerk, International Exchange Service.

DR. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE NATIONAL ZOOLOGICAL PARK

Sir: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ending June 30, 1931:

The regular appropriation made by Congress for the maintenance of the park was $220,520, an increase of $17,520 over 1930. In order that plans and specifications might be prepared for a small mammal house before the convening of the next Congress, $4,500 was appropriated and made immediately available for this purpose. In addition an appropriation of $16,000 was provided in the second deficiency act for new boilers and conduits. The regular appropriation act also reappropriated $9,703 remaining unexpended under the bird-house appropriation of 1928 for grading and the construction of cages adjacent to the bird house. In the 1932 appropriation act $4,500 was also made available immediately upon approval of that act to provide for care of the Evans collection. Thus a total of $255,223 was available during the fiscal year. The regular appropriation, together with the additions, has made it possible to carry out some greatly needed repairs and improvements, and the work of the park has progressed in a very satisfactory manner.

ACCESSIONS

Gifts.—The outstanding gift of the year was the Victor J. Evans collection of 133 species and 244 individuals, which was bequeathed to the United States Government for the National Zoological Park by the late Victor J. Evans.

Mr. Evans for years had been deeply interested in animal life and had formed an unusually fine collection of rarities in his private zoo. These are listed among the donations and include two specimens of the white-crowned guenon (*Cercopithecus petronellae*), an exceedingly rare little monkey, regarding which practically nothing is known.

Mr. Evans had previously donated many rare species to the Zoo, among them the glacier bear, almost unique in captivity.

The reptile house created a great deal of interest throughout America, and a steady stream of gifts for the exhibition has been coming in ever since the house has been open.

Foster H. Benjamin, engaged in field work in Florida for the United States Department of Agriculture, has sent in many fine specimens; and we have profited very much through the field trips of Dr. Charles E. Burt, of Waxahachie, Tex., who has sent us the specimens picked up that he thought would be interesting to the Park. Dewey Moore, of Indio, Calif., has been on the alert and has sent a number of valuable specimens that we could not otherwise have obtained.

William K. Ryan, of Washington, D. C., a fancier of rare birds, has presented several especially desirable species.

The San Diego Zoo, of San Diego, Calif., contributed a collection of some of the California species of reptiles that are difficult to obtain.

In the late fall the director, on his vacation, visited Central America, and while at Tela, Honduras, he was presented such species as seemed desirable from the famous Tela Serpentarium. R. E. Stadelman, in charge of the laboratory, accompanied him on field collecting trips. The United Fruit Co. greatly facilitated the work, and thanks are due to R. K. Thomas and Dr. R. P. MacPhail for kindly hospitality and much aid. Incidentally the director collected various small species and through the aid of the honorable Secretary of Agriculture of Cuba and the chief of the Oficina Sanidad Vegetal, Ernesto Sanchez Estrada, was enabled to bring home a flock of 20 Cuban flamingoes. The entire collection obtained on this trip was transported by the United Fruit Co. free of charge to New York, and every possible facility for the proper care of the specimens was afforded. This was most valuable assistance, which enabled the successful landing of specimens that might not otherwise have been procurable.

The United States Biological Survey of the Department of Agriculture and numerous members of its staff have contributed specimens to the Zoo and have assisted in making arrangements for other parties to supply us with specimens.

Dr. Alexander Wetmore and Frederick C. Lincoln on a trip to Haiti obtained and presented several specimens of two species of lizards not seen before in captivity.

An outstanding gift was that of three beautiful specimens of Kodiak bear cubs collected and presented by Senator Frederick Hale, of Maine. He caught these and brought them personally to Washington, where they are now thriving. As the National Zoological Park endeavors to maintain an especially good collection of Alaskan bears these cubs are a highly appreciated addition.

Practically all the plants placed in the reptile house as setting for animals were gifts from various branches of the United States Government and private individuals. The larger contributors were:

Bureau of Plant Industry of the Department of Agriculture, the Office of Public Buildings and Public Parks, the United States Botanic Garden, Walter Reed Hospital, and San Diego Zoo.

ENDOWMENTS

The first endowments ever received by the Zoo were two given during the fiscal year 1931. The Frances Brincklé Zerbee Memorial Fund of $1,000 was given to the Smithsonian Institution by Maj. Leigh Zerbee, her husband, for the use of the National Zoological Park to maintain stock in aquariums. Mrs. Zerbee was particularly interested in fishes and other small aquatic forms and it was in recognition of her keen interest in such matters that Major Zerbee established this memorial fund. A bronze tablet has been placed in the reptile house over the aquaria in which this stock is to be maintained.

William S. Barstow of Great Neck, Long Island, presented $1,000 as an endowment in the name of his son, Frederic D. Barstow. This money has been invested and the income from it will be used to keep a cage in the zoo stocked with some interesting small mammal. Frederic D. Barstow, who died soon after this fund was established, was a keen enthusiast regarding birds and mammals and had made several trips to the Tropics for the purpose of collecting them.

The only previous contribution to the Zoo at all similar in character was the construction of the Beatrice Henderson cage for birds. This cage was built during the summer of 1912 by the late John B. Henderson, jr. It is about 24 by 40 by 26 feet, situated near the great flight cage, and now houses cockatoos of various kinds.

DONORS AND THEIR GIFTS

Thomas D. Bacon, Washington, D. C., woodchuck.

Dr. Paul Bartsch, Washington, D. C., 21 Bahama iguanas, 119 hermit crabs, 2 common iguanas, 4 marine turtles.

R. L. Bassett, Glenn Dale, Md., barred owl.

Dr. B. L. Beaines, Richmond, Va., great horned owl.

H. W. Belt, Hyattsville, Md., king snake.

J. E. Benedict, jr., N. C., 2 marbled salamanders.

Foster H. Benjamin, Orlando, Fla., through United States Department of Agriculture, bull snake, 2 worm lizards, garter snake, pine snake, diamond-back rattlesnake, 2 hog-nosed snakes, water moccasin, ground rattlesnake, water snake, green snake, 2 indigo snakes, pigmy rattlesnake, 4 soft-shell turtles, 5 gopher tortoises, salamander, 4 alligators, bat, 3 frogs, 7 Florida box tortoises, painted turtle, Florida snapping turtle, Osceola snapping turtle, 2 fence lizards, 14 Florida cooters, musk turtle.

Jim Black, Pine Castle, Fla., 12 Florida cooters, 2 soft-shell turtles.

S. Bolay, New Orleans, La., 2 Texas king snakes.

Miss Isabelle Borders, Okmulgee, Okla., scarlet milk snake.

J. S. C. Boswell, Alexandria, Va., painted turtle, spotted turtle, 2 mole snakes.

M. K. Brady, Washington, D. C., painted turtle.

Edward E. Brand, Chambersburg, Pa., pilot snake.

F. R. Brown, Miami, Fla., water snake.

E. J. and S. K. Brown, Eustis, Fla., pine snake, king snake.

Dr. Charles E. Burt, Waxahachie, Tex., 5 Texas tree toads, California bull snake, 2 horned lizards, *Coleonyx brevis*, *Holbrookia propinqua*, 3 collared lizards, blind snake, spotted race runner, desert snake, ribbon snake, ringed snake, king snake, 2 western bull snakes, *Lampropeltis getulus holbrooki*, *Leiolopisma laterale*, *Natrix grahamii*, *Sceloporus undulatus undulatus*, DeKay's snake, *Tantilla gracilis*, *Thamnophis sauritus proximus*.

Miss Jane Cain, Washington, D. C., 2 alligators.

J. R. Cargill, Columbus, Ga., opossum.

F. G. Carnochan, New York, N. Y., 5 wood turtles.

E. B. Chamberlain, Charleston, S. C., 2 tree boas, 2 chicken snakes.

Mr. Chestnut, Hyattsville, Md., 2 opossums.

Miss Doris M. Cochran, Washington, D. C., 4 water snakes.

Colon Humane Society, through A. H. Pinney, Christobal, Canal Zone, gray fox.

Roger Conant, Toledo, Ohio, 2 fox snakes.

W. W. Conn, Washington, D. C., double-crested cormorant.

L. C. Cook, San Diego, Calif, 12 western swifts.

S. S. Crossley, through United States Biological Survey, Manila, Ark., blue goose.

Dr. J. F. Crowley, Washington, D. C., 2 alligators.

Mr. Curtis, Washington, D. C., screech owl.

Mrs. N. C. Damon, Chevy Chase, Md., alligator.

A. Mercer Daniel, Washington, D. C., scaup.

R. C. Deckert, Miami, Fla., blue-tailed skink.

William Domdera, Washington, D. C., emperor boa.

Vernon Dorman, Washington, D. C., 4 horned lizards.

W. I. Doty, through United States Forest Service, Washington, D. C., porcupine.

Mrs. B. M. Dugdale, Ashland, Va., Singapore grass monkey.

Charles Eaton, Washington, D. C., fence lizard.

David Eckhardt and Edwin Lecarpentir, Washington, D. C., water snake.

Dr. William O. Emery, Washington, D. C., 5 edible frogs, serrated frog, 7 midwife toads, 2 blind worms, European painted frog.

E. R. Erwin, Washington, D. C., Cooper's hawk.

Victor J. Evans bequest, Washington, D. C.:

Common emu	1	Mallard duck	11
Brown pelican	1	White-fronted goose	2
European pelican	2	Brant	1
Rose-colored pelican	1	Canada goose	1
American egret	1	Hutchins goose	1
Roseate spoonbill	1	Bernacle goose	4
White ibis	2	Ruddy shelldrake	1
Scarlet ibis	1	Blue goose	2
Boat-billed heron	1	Snow goose	1
Black-crowned night heron	1	Coscoroba goose	1
American flamingo	1	Mute swan	1
Sacred ibis	1	Tree duck	1
Wood duck	3	White-faced tree duck	1
Egyptian goose	2	Bar-headed goose	2
Formosan teal	1	Baldpate or widgeon	1

Yellow-billed teal	2	Hyacinthine macaw	1
Redhead	2	Australian king parrot	1
Canvasback	1	Illiger's macaw	2
Blue-wing teal	1	Red, blue, and yellow macaw	1
Red-breasted goose	1	Mexican green macaw	1
Shelldrake	1	Yellow paroquet	2
Ducks (not identified)	2	Long-tailed paroquet	1
Spurwing goose	1	Nepalese paroquet	1
Call duck	1	Spix's macaw	1
Vulturine guineafowl	1	Hawk-headed parrot	1
Lady Amherst's pheasant	5	Blue-cheeked lory	2
Golden pheasant	3	Red-headed parrot	1
Panama curassow	1	Blue-eared lory	2
Brown-eared pheasant	2	Cockateel	2
Chinese silver pheasant	22	Common lory	2
Swinhoe's pheasant	5	Kea	1
Himalayan Impeyan pheasant	1	Beautiful lory	1
Malay fireback pheasant	1	Regents parrot	1
Wild turkey	5	Blue-winged conure	2
Razor-billed curassow	1	Forstens paroquet	1
Chachalaca	3	Green-naped lory	2
Blue Indian peafowl	1	Ariel toucan	1
Ring-necked pheasant	17	King bird of paradise	1
Green Japanese pheasant	3	Old World raven	1
Crested jungle quail	1	12-wired bird of paradise	1
Reeve's pheasant	3	Red kangaroo	1
Domestic turkey	3	White-crowned guenon	2
Junglefowl	1	Mustache monkey	1
Demoiselle crane	2	DeBrassa's guenon	1
Crowned crane	2	Mona monkey	1
Cariama	1	Macaque	1
Saras crane	2	Talapoin monkey	1
Siberian crane	1	American beaver	3
Lesser adjutant	1	Spring buck	1
New Zealand mud hen	2	Indian antelope or black buck	2
Stanley or paradise crane	1	Axis deer	2
Ruff	1	White-tailed gnu	2
Nicobar pigeon	2	White fallow deer	4
Sclater's crowned pigeon	4	Chapman's zebra	3
Victoria crowned pigeon	1	Tahr	1
Common turtle dove	1	Mouflon	1
Pigeon	13	East African bush pig	2
Donaldson's turacou	1	Eland	9

Dr. H. E. Ewing, Washington, D. C., tarantula.
T. N. Fielder, Washington, D. C., alligator.
Miss Phoebe B. Fleming, Washington, D. C., Santo Domingo parrot.
W. H. Florence, Clarendon, Va., tarantula.
Miss Edith R. Force, Tulsa, Okla., 6 green snakes, 2 garter snakes.
Marion Foresman, Tulsa, Okla., blue racer.
Franklin Zoological Park, Boston, Mass., Jamaican iguana.

Mrs. R. C. Frink, Hyattsville, Md., alligator.
Carlos P. Fweninger, Washington, D. C., alligator.
H. J. Gibson, Washington, D. C., black snake.
Miss Martha Glenn, Washington, D. C., alligator.
W. Grange, Tucson, Ariz., 7 green toads.
Charles A. Graves, Washington, D. C., black snake.
David H. Greene, Tulsa, Okla., king snake.
Louis Guilini, Washington, D. C., tree frog.
Hagenbeck Bros., Stellingen, Germany, 9 assorted European snakes.
Senator Frederick Hale, Maine, 3 Kodiak bears.
Jesse Hand, Belleplains, N. J., pinesnake.
A. H. Hardisty, Washington, D. C., 4 green frogs, water snake, 3 dusky salamanders, 6 red salamanders.
Verna and John Hazzard, Washington, D. C., prairie dog.
T. S. Hess, Washington, D. C. fence lizard.
Mrs. W. F. Hirst, Takoma Park, Md., opossum.
W. B. Hitt, Washington, D. C., alligator.
George E. Holman, Salt Lake City, Utah, through the United States Biological Survey, cinnamon bear.
Miss Suzanne Holt, Washington, D. C., alligator.
President Herbert Hoover, The White House, red-shouldered hawk.
Miss Mary K. Hoover, Washington, D. C., alligator.
Lieut. Edward T. Hughes, Washington, D. C., white rabbit.
R. H. Hutchison, Glenolden, Pa., 4 Florida diamond-back rattlesnakes, Texas rattlesnake, copperhead, water moccasin.
James Hyslop, Silver Spring, Md., 2 mole snakes.
Roy Jennier, Alexandria, Va., hog-nosed snake.
Mrs. Luther Johnson, Washington, D. C., grass paroquet.
Wheeler Johnson, Washington, D. C., alligator.
Ellis S. Joseph, New York, N. Y., 2 green-flanked caiques.
T. C. King, Takoma Park, Md., barred owl.
W. A. King, Brownsville, Tex., fer-de-lance.
Mrs. Phoebe Knappen, Washington, D. C., box tortoise.
F. H. Knight, Washington, D. C., marine turtle.
R. S. Koffman, Washington, D. C., great horned owl.
Samuel Kress, Costa Rica, through United Fruit Co., 2 deer, emperor boa.
Miss Ellen LaMotte, Washington, D. C., hawk-headed parrot.
Lansburgh & Bro., boys' department, alligator.
Major Larsen, United States Marine Corps, Quantico, Va., red, yellow, and blue macaw.
Edward Layton, Florence, S. C., 3 alligators.
Commander Leechel, United States Navy, Washington, D. C., turtle.
B. A. Levitan, Washington, D. C., alligator.
Ardale Martz, Madison, Va., barn owl.
Marine Corps, Qauntico, Va., through Maj. K. I. Buse, cinnamon bear.
Judge Robert E. Mattingly, Washington, D. C., 2 Florida diamond-back rattlesnakes.
J. T. McBurney, Chevy Chase, Md., opossum.
Henry J. McDermott, Takoma Park, Md., 8 bats.
E. A. McIlhenny, Avery Island, La., 11 pintail ducks, 1 hybrid duck, 10 blue-winged teals, 2 lesser scaups.

E. B. McLean, Washington, D. C., great red-crested cockatoo.

Mrs. F. McManamy, Washington, D. C., screech owl.

F. A. Meatyard, Washington, D. C., Tovi paroquet.

E. G. Meyer, Washington, D. C., raccoon.

Kenneth Meyers, Tacoma Park, Md., common lizard, 5 common frogs, 2 water snakes.

Michigan Department of Conservation, game branch, 2 beavers.

Miss Dorothy Miller, Washington, D. C., alligator.

Dr. G. S. Miller, Washington, D. C., 3 Jamaican tree snails.

W. W. Minear, Quincy, Ill., 14 banded rattlesnakes, blacksnake, ribbon snake, water snake.

Robert B. Montgomery, Washington, D. C., grivet monkey.

Dewey Moore, Indio, Calif., through Bureau of Plant Industry, 9 giant hairy scorpions, 7 sidewinder rattlesnakes, 4 desert rattlesnakes, 2 California spotted lizards, horned lizard, Agassiz's tortoise, California bullsnake, spiny-swift, 4 lizards.

Mr. Morefield, Amelia, Va., owl.

W. C. Morin, Petersburg, Va., 2 alligators.

W. C. Morrill, Washington, D. C., crow.

John Marshall Newton, Washington, D. C., alligator.

Dr. G. K. Noble, New York, N. Y., 3 eyed lizards, chicken snake, 2 pilot snakes.

Robert and James Nye, Washington, D. C., hermit crab, alligator.

Miss Ott, Washington, D. C., barred owl.

Dr. S. L. Owens, Washington, D. C., screech owl.

Dr. Parker, Heyeres, France, green lizard.

James Parmelee, Washington, D. C., silver pheasant.

F. M. Pearson, Baltimore, Md., horned lizard.

S. F. Perkins, Washington, D. C., 7 ribbon snakes, 42 spotted turtles, 5 black-snakes, garter snake, 7 water snakes, stone snake. Valeria snake.

Philadelphia Zoological Park, Philadelphia, Pa., Matamata turtle, Muhlenberg's turtle.

Hon. Gifford Pinchot, Washington, D. C., 5 Galapagos Island tortoises.

Mr. Polock, Skyland, Va., milk snake.

Prichards Flower Store, Washington, D. C., banded rattlesnake.

Harry Prichard, Washington, D. C., small snake.

Miss Lillian Radionoff, Washington, D. C., 2 canaries.

Carl Rao, Washington, D. C., scorpion.

Mrs. J. A. Raum, Washington, D. C., barred owl.

Wm. Richards, Washington, D. C., barred owl.

H. C. Ritenour, Thurmont, Md., 2 fox snakes.

Dr. George B. Roth, Washington, D. C., 15 painted turtles.

Miss Mary Ruden, Washington, D. C., marmosette.

Paul Ruthling, Sante Fe., N. Mex., red racer.

Wm. K. Ryan, Washington, D. C., 2 blue-bellied lories, 2 angel fish, sulphur crested cockatoo, crested starling, 2 blue honey creepers.

C. O. Samuelson, Virginia Highlands, Va., margaycat.

San Diego Zoological Park, San Diego, California, 3 San Diegan gopher snakes, 3 California boas, 2 California king snakes, 4 Boyle's king snakes, Pacific rattlesnake, 2 desert rattlesnakes, 3 western bull snakes, 3 red rattlesnakes,

2 sidewinder rattlesnakes, tricolor ground snake, 2 green toads, *Crotalus confluentus oreganus, Crotalus confluentus mitchellii, Masticophis lateralis, Masticophis flagellum frenatus, Gerrhonotus scincicauda webbii, Sceloporus magister, Phrynosoma platyrhinos, Phrynosoma m'callii.*

F. C. Scheppach, Washington, D. C., woodchuck.

Edward S. Schmid, Washington, D. C., black snake.

Mrs. Jouett Shouse, Washington, D. C., alligator.

Edward Skinner, Takoma Park, D. C., banded rattlesnake.

G. T. Smallwood, Washington, D. C., marine turtle.

Capt. W. Bedell Smith, U. S. A., Luzon, Philippine Islands, 3 Javan macaques, 2 Japanese monkeys.

Mrs. W. Bedell Smith, Luzon, Philippine Islands, Palawan peacock-pheasant.

Don Spangenberg, White Mills, Pa., barred owl.

Miss Louise Spencer, Ashland, Pa., smooth greensnake.

H. V. Stabler, Chevy Chase, Md., barred owl.

St. Louis Zoological Park, St. Louis, Mo., alligator, snapping turtle.

Harry Stokes, through United States Biological Survey, Grants Pass., Oreg., puma.

J. R. Sweeny, Washington, D. C., 3 alligators.

Capt. Edward Sykes, Washington, D. C., 2 golden-tailed parrots.

Dr. W. P. Taylor, through United States Biological Survey, Tucson, Ariz., worm snake.

Tela Serpentarium, Tela, Honduras, 2 neotropical rattlesnakes, 4 fer-de-lance, 10 iguanas, spiny-tailed black iguana, indigo snake, Rossignon's snapping turtle, tropical king or false coral snake, 2 coral snakes, Guatemalan terrapin, Mexican moccasin, green tree snake, 2 pike-headed tree snakes, green basilisk, banded basilisk.

Henry and John Thies, Beltsville, Md., red-tailed hawk.

R. E. Thomas, Washington, D. C. alligator.

Miss Mary Tillman, Washington, D. C., ortolan.

Dr. A. C. Tollinger. Philadelphia, Pa., yellow-naped parrot.

United States Biological Survey, 2 Virginia deer, 3 prong-horn antelopes, 6 Canada geese.

United States Bureau of Fisheries, 8 diamond-back terrapins.

University of Michigan, Ann Arbor, Mich., through Mrs. Helen T. Gaige, Department of Zoology, 12 Blanding's turtles.

Mrs. V. M. Van Every, Clarendon, Va., gray squirrel.

Mrs. V. C. Vance, Washington, D. C., canary.

W. M. Wales, Washington, D. C., alligator.

R. A. Walton, Monteverde, Fla., osceola, snapping turtle.

War Department, The General Staff, alligator.

F. A. Ward, Washington, D. C., alligator.

Mrs. Peter C. Warwick, Richmond, Va., capuchin monkey.

Dr. A. Wetmore and F. C. Lincoln, 7 Beata curl-tail lizards, 4 Abbott's swift.

J. H. Willhite, through United States Biological Survey, hybrid wolf.

H. P. Williams, through United States Biological Survey, 8 timber wolves.

Dr. E. C. Wilson, Washington, D. C., great horned owl.

B. Wright, Ashland, Va., opossum.

J. R., jr., and Howard E. Wulsin, Washington, D. C., 3 alligators.

Dr. James Zetek, Ancon, Canal Zone, 2 emperor boas.

Donors unknown, nighthawk, alligator.

Births.—There were 60 mammals born and 14 birds hatched in the park during the year. These include the following:

MAMMALS

Æpyprymnus rufescens	Rat kangaroo	1
Ammotragus lervia	Aoudad	2
Axis axis	Axis deer	1
Bison bison	American bison	2
Canis latrans	Coyote	2
Canis nubilus	Plains wolf	11
Capra ibex	Ibex	1
Cervus elaphus	Red deer	5
Connochaetes taurinus albojubatus	White-bearded gnu	1
Dama dama	Fallow deer	1
Dasyprocta agouti	Common agouti	1
Dasyprocta punctata	Speckled agouti	2
Dasyprocta rubrata	Trinidad agouti	1
Felis leo	Lion	10
Felis pardus suahelicus	East African leopard	2
Hylobates leucogenys	White-cheeked gibbon	1
Lama glama	Llama	2
Nasua narica	Coatimundi	4
Odocoileus costaricensis	Costa Rican deer	1
Ovis canadensis	Rocky Mountain sheep	1
Ovis europaeus	Mouflon	1
Phacochoerus aethiopicus	Wart hog	4
Sika nippon	Japanese deer	3

BIRDS

Anas domestica	Pekin duck	3
Branta canadensis	Canada goose	7
Pica pica hudsonia	American magpie	4

Many species of reptiles deposited eggs since being moved into their new quarters in the reptile house, and a few hatched after June 30, but there were no natural increases in the stock during the year.

Early Easter morning an African python laid about two dozen eggs and incubated them for a period of two months. Unfortunately, however, they proved to be infertile. This was of considerable scientific as well as popular interest.

Purchases and exchanges.—The principal purchases this year have been a male black African rhinoceros, a specimen of the rare babirussa, a pair of raccoon dogs, a Bornean gray gibbon, a Siamang gibbon, and a white-handed gibbon. The last three were purchased under the Walter P. Chrysler fund. At the time these animals were acquired the Zoo had a pair of white-cheeked gibbons and their young, which gave us a total of 4 species of gibbons on exhibition at one time.

The rhinoceros has apparently adapted himself to our conditions and has made a splendid growth.

A quantity of reptiles were purchased for the opening of the new building. Chief among these is a magnificent king cobra, measuring 14 feet 6 inches in length. This was secured six months before we had quarters for it, but Dr. Raymond L. Ditmars, of the New York Zoological Park, very kindly took care of it during this time and then brought it down personally.

A number of small exchanges have been made, but the most interesting was that of a polar bear which was received from the Zoological Park of Edinburgh. This is a male which has been placed with Marian, a young female of the same species.

REMOVALS

Causes of death.—When it has been thought that determination of the cause of death of certain animals might be useful, the specimens have been submitted to the pathological division of the Bureau of Animal Industry for examination. The following list shows the results of the autopsies:

MAMMALS

Artiodactyla: Obstruction in the oesophagus, 1; odema of the heart and pericardium, 1; chronic pneumonia, 1; liver spotted with tubercules, indications of tuberculosis, 1.

Carnivora: Gastro-enteritis, 1; multiple body abscesses, 1; enteritis, 1.

Primates: Gastritis and ulcerated pyloric knob, 1.

BIRDS

Ciconiiformes: Enteritis, 1.

Pelecaniformes: Internal hemorrhage, 1.

Psittaciformes: Tuberculosis, 1.

ANIMALS IN THE COLLECTION JUNE 30, 1931

Mammals

MARSUPIALIA

Æpyprymnus rufescens	Rat kangaroo	3
Didelphis virginiana	Opossum	9
Macropus robustus	Wallaroo or euro kangaroo	1
Macropus rufus	Great red kangaroo	2
Phascolomys mitchelli	Wombat	1

CARNIVORA

Acinonyx jubatus	Cheeta	1
Arctictis binturong	Binturong or bear cat	1
Bassariscus astutus	Cacomixtle or ring tail	2
Canis dingo	Dingo	1
Canis latrans	Coyote	10
	Albino coyote	1
Canis mesomelas	Black-backed jackal	1

Canis nubilus	Wolf	18
Canis nubilus domesticus	Wolf+dog hybrid	1
Crocuta crocuta germinans	East African spotted hyena	1
Euarctos americanus	American black bear	3
	Cinnamon bear	4
Euarctos emmonsii	Glacier bear	1
Felis capensis hindei	East African serval	2
Felis concolor azteca	Mexican puma	2
Felis concolor oregonensis	Puma	1
Felis leo	Lion	10
Felis onca	Jaguar	2
	Black jaguar	1
Felis pardalis	Ocelot	1
Felis pardalis brasiliensis	Brazilian ocelot	1
Felis pardalis var	Ocelot	1
Felis pardus	Black leopard	1
Felis pardus suahelicus	East African leopard	6
Felis serval	Serval	1
Felis tigris	Bengal tiger	1
Felis tigris longipilis	Manchurian tiger	1
Genetta dongalana neumanni	Neumann's genet	2
Gulo luscus	Wolverine	1
Helarctos malayanus	Sun bear	2
Herpestes ichneumon	Egyptian mongoose	1
Hyaena brunnea	Brown hyena	2
Lutra canadensis vaga	Florida otter	1
Lynx baileyi	Bailey's lynx	1
Lynx caracal	Caracal	1
Lynx rufus	Bay lynx	2
Mellivora capensis	Ratel	1
Mephitis nigra	Skunk	2
Mustela furo	Ferret	1
Nasua narica	Gray coatimundi	8
Nasua sp	Coatimundi	1
Nasua sp	Brazilian coatimundi	1
Nyctereutes procyonoides	Raccoon dog	3
Paradoxurus philippensis	Philippine palm civet	5
Potos flavus	Kinkajou	4
Procyon cancrivorus	Crab-eating raccoon	2
Procyon lotor	Raccoon	23
Proteles cristatus	Aard-wolf	1
Taxidea taxus	American badger	2
Tayra barbara	Tayra	1
Thalarctos maritimus	Polar bear	4
Urocyon cinereoargenteus	Gray fox	2
Urocyon sp	Gray fox	1
Ursus apache	Apache grizzly	1
Ursus arctos	European brown bear	6
Ursus gyas	Alaska Peninsula brown bear	4
Ursus horribilis	Grizzly bear	1
Ursus kidderi	Kidder's bear	2
Ursus middendorffi	Kodiak bear	5
Ursus sitkensis	Sitka brown bear	3

Ursus thibetanus	Himalayan bear	2
Viverra civetta	Civet	1
Viverra tangalunga	Tangalunga	1
Vulpes fulva	Red fox	4
	Silver fox	1

PINNIPEDIA

Callorhinus alascanus	Northern fur seal	2
Phoca richardi	Pacific harbor seal	3
Zalophus californianus	California sea lion	3

PRIMATES

Aotus trivirgatus	Douroucouli	1
Ateles geoffroyi	Gray spider monkey	2
Ateles sp	Spider monkey	1
Callithrix jacchus	Marmosette	1
Cebus capucinus	White-throated capuchin	4
Cebus unicolor	Gray or grizzled capuchin	3
Cercocebus fuliginosus	Sooty mangabey	4
Cercopithecus albigularis	Sykes's or blue monkey	4
Cercopithecus brazzae	De Brazza's guenon	1
Cercopithecus callitrichus	Green guenon	2
Cercopithecus cephus	Mustache monkey	1
Cercopithecus griseoviridis	Grivet monkey	4
Cercopithecus l'hoesti	Killimbira guenon	1
Cercopithecus mona	Mona monkey	4
Cercopithecus petaurista	Lesser white-nosed guenon	2
Cercopithecus petronellae	White-crowned guenon	1
Cercopithecus pygerythra	Vervet	1
Cercopithecus roloway	Roloway monkey	1
Gorilla gorilla	Gorilla	1
Hylobates leucogenys	White-cheeked gibbon	2
Lemur rufifrons	Red-fronted lemur	1
Leontocebus rosalia	Silky or lion-headed marmosette	2
Macaca andamanensis	Burmese macaque	1
Macaca fuscata	Japanese monkey	5
Macaca irus	Crab-eating macaque	2
Macaca mordax	Javan macaque	2
Macaca mulatta	Rhesus monkey	5
Macaca nemestrina	Pig-tailed monkey	1
Macaca speciosa	Red-faced monkey	1
Macaca syrichta	Philippine monkey	3
Magus maurus	Moor monkey	2
Mandrillus leucophæus	Drill	1
Mandrillus sphinx	Mandrill	3
Miopithecus talapoin	Talapoin monkey	1
Pan satyrus	Chimpanzee	2
Papio anubis	Anubis or yellow baboon	1
Papio hamadryas	Hamadryas baboon	1
Papio neumanni	Olive baboon	1
Papio porcarius	Chacma	2
Simia sylvanus	Barbary ape	1

RODENTIA

Acanthion brachyurum	Malay porcupine	2
Castor canadensis	American beaver	5
Cavia porcellus	Domestic guinea pig	25
Citellus tridecemlineatus	Thirteen-lined ground squirrel	2
Cuniculus paca virgatus	Central American paca	4
Cynomys ludovicianus	Prairie dog	6
Dasyprocta punctata	Speckled agouti	2
Dasyprocta rubrata	Trinidad agouti	4
Dolichotis patagonica	Patagonian cavy	2
Dolichotis salinicola	Dwarf cavy	2
Erethizon dorsatum	Eastern porcupine	1
Glaucomys volans	Flying squirrel	3
Hydrochœrus hydrochœrus	Capybara	1
Hystrix africæaustralis	African porcupine	3
Lagostomus trichodactylus	Viscacha	2
Marmota monax	Woodchuck	1
Sciurus carolinensis	Gray squirrel	1
	Albino gray squirrel	2
Sciurus niger	Fox squirrel	1

LAGOMORPHA

Oryctolagus cuniculus	Domestic rabbit	5

ARTIODACTYLA

Æpyceros melampus suara	East African impalla	2
Ammotragus lervia	Aoudad or Barbary sheep	5
Anoa depressicornis	Anoa	1
Antilocapra americana	Prong-horn antelope	3
Antilope cervicapra	Black buck or Indian antelope	3
Axis axis	Axis deer	5
Babirussa alfurus	Babirussa	1
Bison bison	American bison or buffalo	11
Bos indicus	Zebu	1
Boselaphus tragocamelus	Nilgai	2
Bubalus bubalis	Indian buffalo	3
Camelus bactrianus	Bactrian camel	1
Capra hircus	Goat	3
Capra ibex	Alpine ibex	2
Cervus canadensis	American elk or wapiti	5
Cervus elaphus	Red deer	12
Cervus hanglu	Kashmir deer	1
Cervus xanthopygus	Bedford deer	5
Connochætes gnu	White-tailed gnu	2
Connochætes taurinus	Brindled gnu	1
Connochætes taurinus albojubatus	White-bearded gnu	2
Dama dama	Fallow deer	12
	Fallow deer (white)	8
Hemitragus jemlahicus	Tahr	6
Hyelaphus porcinus	Hog deer	3
Lama glama	Llama	8

Lama huanacus	Guanaco	2
Odocoileus columbianus sitkensis	Sitka deer	1
Odocoileus costaricensis	Costa Rican deer	1
Odocoileus hemionus	Mule deer	2
Odocoileus virginianus	Virginia deer	4
Oreamnos americanus	Mountain goat	2
Ovibos moschatus wardi	White-faced musk ox	2
Ovis canadensis	Rocky Mountain sheep	7
Ovis europaeus	Mouflon	7
Pecari angulatus	Peccary	1
Phacochœrus æthiopicus massaicus	East African warthog	3
Poephagus grunniens	Yak	7
Potamochœrus chœropotamus	East African bush pig	2
Rangifer tarandus	Reindeer	3
Rucervus duvaucelii	Barasingha	7
Rucervus eldii	Burmese deer	1
Rusa moluccensis	Molucca deer	1
Sika nippon	Japanese deer	14
Strepsiceros strepsiceros	Greater kudu	1
Sus scrofa	European wild boar	2
Synceros caffer	South African buffalo	1
Tragelaphus angasi	Inyala	1
Taurotragus oryx	Eland	3

PERISSODACTYLA

Chœropsis liberiensis	Pigmy hippopotamus	2
Equus grevyi-asinus	Zebra-ass hybrid	1
Equus grevyi-caballus	Zebra-horse hybrid	1
Equus onager	Asiatic wild ass or kiang	1
Equus przewalskii	Mongolian wild horse	3
Equus quagga chapmani	Chapman's zebra	5
Equus zebra	Mountain zebra	2
Hippopotamus amphibius	Hippopotamus	1
Rhinoceros bicornis	Black rhinoceros	1
Tapirella bairdii	Baird's tapir	1
Tapirus terrestris	Brazilian tapir	1

PROBOSCIDEA

Elephas sumatranus	Sumatra elephant	1
Loxodonta africana oxyotis	African elephant	1

EDENTATA

Dasypus novemcinctus	9-banded armadillo	1

Birds

RATITAE

Casuarius unipendiculatus	Single wattled cassowary	2
Dromiceius novaehollandiae	Common emu	3
Rhea americana	Common rhea or nandu	1
Struthio australis	South African ostrich	3
Struthio camelus	Nubian ostrich	1

PELECANIFORMES

Anhinga anhinga	Anhinga or snake bird	1
Pelecanus californicus	California brown pelican	4
Pelecanus conspicillatus	Australian pelican	1
Pelecanus erythrorhynchos	American white pelican	10
Pelecanus occidentalis	Brown pelican	4
Pelecanus onacrotalus	European pelican	4
Pelecanus roseus	Rose-colored pelican	2
Phalacrocorax auritus floridanus	Florida cormorant	1

CICONIIFORMES

Ajaja ajaja	Roseate spoonbill	2
Ardea goliath	Goliath heron	2
Ardea herodias	Great blue heron	3
Ardea occidentalis	Great white heron	1
Balaeniceps rex	Shoebill stork	1
Cochlearius cochlearius	Boatbill	3
Ephippiorhynchus senegalensis	Saddle-billed stork	1
Guara alba	White ibis	9
Guara rubra	Scarlet ibis	3
Heroidias egretta	American egret	1
Leptoptilus crumeniferus	Maribou	1
Leptoptilus dubius	Indian adjutant	1
Leptoptilus javanicus	Lesser adjutant	2
Mycteria americana	Wood ibis	1
Nycticorax nycticorax naevius	Black-crowned night heron	30
Phoenicopterus ruber	American flamingo	11
Threskiornis aethippicus	Sacred ibis	3
Threskiornis melanocephalus	Black-headed ibis	2

ANSERIFORMES

Aix sponsa	Wood duck	1
Alopochen aegyptiacus	Egyptian goose	3
Alopochen jubatus	Orinoco goose	1
Anas domestica	Peking duck	3
Anas platyrhynchos	Mallard	34
Anas rubripes	Black or dusty mallard	2
Anas undulata	African yellow-billed duck	2
Anser albifrons	White-fronted goose	4
Anser brachyrhynchus	Pink-footed goose	1
Anser cinereus domestica	Toulouse goose	2
Anser fabalis	Bean goose	2
Branta bernicla glaucogastra	Brant	6
Branta canadensis	Canada goose	22
Branta canadensis hutchinsii	Hutchins's goose	1
Branta canadensis minima	Cackling goose	2
Branta canadensis occidentalis	White-cheeked goose	31
Casarca variegata	Paradise duck	1
Chaulelasmus streperus	Gadwall	2
Chen caerulescens	Blue goose	4
Chenopis atrata	Black swan	3
Coscoroba candida	Coscoroba goose	1

Cygnopsis cygnoides	Chinese goose	1
Cygnus columbianus	Whistling swan	3
Cygnus gibbus	Mute swan	2
Dafila acuta	Pintail	6
Dafila bahamensis	Bahama pintail	2
Dendrocygna arborea	West Indian tree duck	4
Dendrocygna autumnalis	Black-bellied tree duck	1
Dendrocygna eytoni	Eyton's tree duck	3
Dendrocygna viduata	White-faced tree duck	1
Eulabia indica	Bar-headed goose	1
Mareca americana	Baldpate	3
Marila americana	Redhead	2
Marila marila	Scaup	1
Marila valisineria	Canvas-back	2
Metopiana peposaca	Rosy-billed pochard	1
Nesochen sandvicensis	Hawaiian goose	1
Nettion carolinense	Green-winged teal	3
Nettion formosum	Baikal teal	4
Philacte canagica	Emperor goose	3
Plectropterus gambensis	Spur-winged goose	4
Querquedula discors	Blue-winged teal	8
Rufibrenta ruficollis	Red-breasted goose	1

FALCONIFORMES

Aegypius monachus	Cinereous vulture	2
Aquila chrysaetos	Golden eagle	3
Buteo borealis	Red-tailed hawk	3
Buteo lineatus	Red-shouldered hawk	1
Buteo platypterus	Broad-winged hawk	3
Cathartes aura	Turkey vulture	3
Coragyps atratus	Black vulture	2
Elanus caeruleus	White kite	1
Falco peregrinus	Peregrine falcon	1
Falco sparverius	Sparrow hawk	2
Gymnogyps californianus	California condor	3
Gyps rueppelli	Ruppell's vulture	2
Haliaeetus leucocephalus	Bald eagle	11
Haliastur indus	Malay Brahminy kite	1
Milvus migrans	Yellow-billed kite	1
Polyborus cheriway	Audubons caracara	4
Pseudogyps africanus	White-headed vulture	1
Sagittarius serpentarius	Secretary bird	1
Sarcoramphus papa	King vulture	1
Terathopius ecaudatus	Bateleur eagle	1
Torgos tracheliotus	African eared vulture	4
Uroaetus audax	Wedge-tailed eagle	2
Vultur gryphus	South American condor	1

GALLIFORMES

Acryllium vulturinum	Vulturine guinea fowl	3
Argusianus argus	Argus pheasant	2
Chrysolophus amherstiae	Lady Amherst's pheasant	5

Chrysolophus pictus	Golden pheasant	3
Colinus virginianus	Bobwhite	1
Coturnix coturnix	Migratory quail	1
Crax globicera	Mexican curassow	2
Crax globulosa	Spixs wattled curassow	2
Crax panamensis	Panama curassow	1
Crossoptilon mantchuricum	Brown-eared pheasant	2
Excalfactoria sinensis	Pigmy quail	2
Gallus sp	Jungle fowl	1
Gennaeus edwardsi	Edward's pheasant	1
Gennaeus nycthemerus	Silver pheasant	13
Gennaeus swinhoei	Swinhoe's pheasant	4
Lophophorus impeyanus	Himalayan Impeyan pheasant	1
Meleagris gallopavo	Wild turkey	3
Mitu mitu	Razor-billed curassow	2
Numida mitrata reichenowi	Reichenow's helmeted guinea fowl	4
Ortalis cinericeps	Gray-headed chachalaca	2
Ortalis leucogastra	White-bellied chachalaca	1
Pavo cristatus	Peafowl	9
	White peafowl	2
Penelope boliviana	Crested guan	2
Phasianus torquatus	Ring-necked pheasant	20
Phasianus versicolor	Green Japanese pheasant	2
Polyplectron napoleonis	Palawan peacock-pheasant	1
Rollulus roulroul	Crested jungle quail	1
Syrmaticus reevesi	Reeve's pheasant	2

GRUIFORMES

Anthropoides virgo	Demoiselle crane	5
Antigone australasiana	Australian crane	2
Balearica gibbiriceps	East African crowned crane	5
Balearica pavonina pavonina	West African crowned crane	2
Cariama cristata	Cariama	1
Dissura episcopus	Woolly-necked stork	1
Eurypyga helias	Sun bittern	1
Fulica americana	Coot	3
Fulica cristata	Knobbed coot	2
Grus antigone	Saras crane	2
Grus canadensis	Little brown crane	1
Grus cinerea	Gray crane	2
Grus leucauchen	White-naped crane	1
Grus leucogeranus	Siberian crane	2
Grus mexicana	Sandhill crane	1
Hypotaenidia philippensis	Lesser rail	1
Megalornis lilfordi	Lilford's crane	1
Microtribonyx ventralis	Black-tailed moor hen	1
Ocydromus australis	South Island weka rail	1
Porphyrio melanotus	New Zealand mud hen	4
Psophia crepitans	Trumpeter	2
Psophia viridis	Green-backed trumpeter	2
Rhynochetos jubatus	Kagu	1

CHARADRIIFORMES

Larus argentatus	Herring gull	5
Larus californicus	California gull	7
Larus novaehollandiae	Silver gull	53
Larus occidentalis	Western gull	6
Œdicnemus bistriatus vocifer	South American stone plover	1
Philomachus pugnax	Ruff	4
Sterna caspia	Caspian tern	2

COLUMBIFORMES

Caloenas nicobarica	Nicobar pigeon	7
Chalcophaps indica	Green-winged dove	1
Columba sp	Doves	2
Columba guinea	Speckled pigeon	3
Columba palumbus	Wood pigeon	3
Gallicolumba luzonica	Bleeding-heart dove	2
Globicera pacifica	Pacific pigeon	1
Goura sclateri	Sclater's crowned pigeon	4
Goura victoria	Victoria crowned pigeon	2
Janthoenas vitiensis	White-throated fruit pigeon	1
Macropygia doreya	New Guinea brown pigeon	1
Oena capensis	Cape dove	1
Streptopelia risoria	Ring-neck dove	2
Streptopelia senegalensis	East African ring-neck dove	5
Turtur risoria	Turtle dove	4
Zenaidura macroura	Mourning dove	7
Zenaidura macroura macroura	West Indian dove	1

CUCULIFORMES

Eudynamis honorata	Indian koel	1
Turacus donaldsoni	Donaldson's turacou	1

PSITTACIFORMES

Agapornis fischeri	Fischer's love bird	2
Agapornis lilianae	Nyassa love bird	5
Agapornis madagascariensis	Gray-headed love bird	1
Agapornis personata	Yellow-collared love bird	1
Agapornis pullaria	Red-faced love bird	2
Agapornis taranta	Abyssinian love bird	3
Amazona sp	------------ parrot	1
Amazona aestiva	Blue-fronted parrot	1
Amazona albifrons	White-fronted parrot	6
Amazona albifrons nana	Lesser white-fronted parrot	2
Amazona amazonica	Orange-winged parrot	3
Amazona arausiaca	Bouquet's parrot	1
Amazona auropalliata	Yellow-naped parrot	3
Amazona farinosa	Mealy parrot	1
Amazona festiva	Festive parrot	1
Amazona leucocephala	Cuban parrot	6
Amazona ochrocephala	Yellow-fronted parrot	8

Amazona ochroptera	Yellow-shouldered parrot	1
Amazona oratrix	Double yellow-head parrot	8
Amazona ventralis	Santo Domingo parrot	3
Amazona viridigenalis	Red-crowned parrot	4
Anodorhynchus hyacinthinus	Hyacinthine macaw	2
Aprosmictus cyanopyzicus	Australian king parrot	1
Aprosmictus erythropterus	Crimson-winged paroquet	1
Ara ararauna	Yellow and blue macaw	7
Ara macao	Red, blue, and yellow macaw	6
Ara maracana	Illiger's macaw	3
Ara mexicana	Mexican green macaw	3
Ara severa	Severe macaw	1
Aratinga rubritorquis	Red-throated conure	1
Aratinga solstitialis	Yellow paroquet	2
Brotogeris jugularis	Tovi paroquet	1
Conurus longicauda	Long-tailed paroquet	3
Conurus nepalensis	Nepalese paroquet	2
Coracopsis nigra	Lesser vasa parrot	1
Coracopsis vasa	Greater vasa parrot	1
Cyanopsittacus spixi	Spix's macaw	3
Deroptyus accipitrinus	Hawk-headed parrot	3
Eclectus pectoralis	Red-headed parrot	1
Eos reticulata	Blue-eared lory	2
Eos rubra	Red lory	1
Eos variegata	Purple lory	1
Eupsittula aurea	Golden-crowned paroquet	2
Eupsittula canicularis	Petz's paroquet	2
Eupsittula jendaya	Jenday paroquet	1
Eupsittula weddellii	Weddell's paroquet	2
Kakatoe alba	White cockatoo	1
Kakatoe galerita	Sulphur-crested cockatoo	2
Kakatoe gymnopis	Bare-eyed cockatoo	1
Kakatoe leadbeateri	Leadbeater's cockatoo	2
Kakatoe moluccensis	Great red-crested cockatoo	2
Kakatoe roseicapilla	Roseate cockatoo	8
Leptolophus novaehollandicus	Cockateel	3
Lorius domicella	Ceram lory	1
Lorius lory	Common lory	1
Melopsittacus undulatus	Grass paroquet	4
Microglossus aterrimus	Great black cockatoo	1
Myopsittacus monachus	Quaker paroquet	2
Nandayus nanday	Nanday paroquet	1
Nestor notabilis	Kea	5
Pionites leucogaster	Green-flanked caique	2
Pionus maximiliani	Maximilian's parrot	1
Pionus menstruus	Blue-headed parrot	2
Pionites xanthomera	Amazonian caique	3
Platycercus elegans	Beautiful lory	1
Platycercus eximius	Rosella paroquet	1
Poicephalus meyeri matschiei	East African parrot	2
Polytelis anthopeplus	Regent's parrot	1
Psephotus haematorrhous	Blue-bonnet paroquet	1
Psittacula guianensis	Green-rumped parrotlet	1

Pyrrhura picta	Blue-winged conure	3
Tanygnathus megalorhynchus	Great-billed paroquet	1
Trichoglossus cyanogrammus	Green-naped lorikeet	4
Trichoglossus forsteni	Forsten's paroquet	4
Trichoglossus novaehollandae	Blue-bellied lory	1
Urochroma surda	Golden-tailed parrot	2

STRIGIFORMES

Bubo bubo	European eagle owl	1
Bubo virginianus	Great horned owl	10
Nyctea nyctea	Snowy owl	1
Otus asio	Screech owl	5
Pulsatrix perspicillata	Spectacled owl	2
Strix varia	Barred owl	12
Tyto alba pratincola	American barn owl	4

CAPRIMULGIFORMES

Chordeiles virginianus	Nighthawks	3

COLIIFORMES

Colius macrurous	Mouse bird or coly	1

CORACIIFORMES

Anthracoceros malayanus	White-browed hornbill	1
Lophoceros jacksoni	Jackson's hornbill	1

PICIFORMES

Ramphastos ariel	Ariel toucan	2
Ramphastos carinatus	Sulphur-breasted toucan	2
Ramphastos culminatus	White-breasted toucan	1
Trachyphonus emini	Emin Pasha's barbet	1

PASSERIFORMES

Acridotheres tristis	Common mynah	1
Aethiopsar cristatellus	Crested mynah	1
Agelaius icterocephalus	Yellow-headed marsh bird	1
Aidemosyne cantans	Tawny waxbill	2
Amadina fasciata	Cut-throat finch	9
Amandava amandava	Strawberry finch	15
Amblyrhamphus holosericeus	Red-headed marsh troupial	1
Ampelis cedrorum	Cedar wax-wing	1
Calocitta formosa	Mexican magpie jay	2
Carduelis carduelis	European goldfinch	2
Chasmorhynchus nudicollis	Naked-throated bell bird	1
Chloris chloris	Greenfinch	1
Cicinnurus regius	King bird of paradise	2
Cissilopha yucatanica	Yucatan jay	1
Corvultur albicollis	White-necked raven	1
Corvus albus	White-breasted crow	2
Corvus brachyrhynchos	American crow	5

Corvus corax sinuatus	American raven	5
Corvus coronoides	Australian crow	1
Cosmopsarius regius	Splendid starling	4
Cyanerpes cyaneus	Blue honey creeper	2
Cyanocitta stelleri diademata	Long-crested jay	1
Cyanocorax pileatus	Pileated jay	2
Diatropura progne	Giant whydah	1
Eromopteryx leucopareia	Fisher's finch lark	1
Foudia madagascariensis	Madagascar weaver	3
Garrulax pectoralis	Black-gorgeted laughing thrush	1
Gracula javana	Hill mynah	1
Gracula religiosa	Southern hill mynah	2
Gymnomystax melanicterus	Bare-jawed troupial	1
Heteropsar albicapillus	White-capped starling	1
Icterus parisorum	Scott oriole	1
Lamprocolius sycobius	Southern glossy starling	1
Lamprocorax metallicus	New Guinea starling	1
Liothrix luteus	Red-billed hill-tit	1
Melanopteryx rubiginosus	Chestnut weaver	27
Mino dumonti	Golden-headed mynah	1
Molpastes haemorrhous	Black-headed bulbul	1
Munia atricapilla	Black-headed nun	1
Munia castaneithorax	Chestnut-breasted finch	1
Munia oryzivora	Java finch	8
Munia punctulata	Nutmeg finch	18
Otocompsa jocosa	Red-eared bulbul	3
Paradisea rubra	Red bird of paradise	1
Paradisornis rudolphi	Prince Rudloph's blue bird of paradise	1
Paroaria cucullata	Red-crested cardinal	2
Parotia lawesi lawesi	Lawes' six-plumed bird of paradise	1
Pica pica hudsonia	Magpie	2
Ploceus intermedieus	Masked weaver	6
Poephila personata	Masked grass finch	1
Pyromelana orix	Red-crowned bishop bird	2
Quelea sanguinirostris intermedia	Southern masked weaver finch	43
Schlegelia wilsoni	Wilson's bird of paradise	1
Seleucides niger	12-wired bird of paradise	3
Semioptera wallacei	Wallace's bird of paradise	1
Serinus canarius	Canary	11
Sicalis flaveola	Saffron finch	1
Steganura paradisea	Paradise whydah	1
Struthidea cinerea	Australian gray jumper	1
Sturnus vulgaris	Starling	2
Taeniopygia castanotis	Zebra finch	1
Trochalapteron canorum	Brown laughing thrush	1
Urobrachya phoeniceia	Chestnut-winged whydah	1
Urocissa occipitalis	Red-billed blue magpie	3
Vidua macroura	Pintail whydah	2
Xanthoura luxuosa	Green jay	1
Xanthoura luxuosa sub. sp	Nicaragua green jay	1

Reptiles

CHELONIA

Amyda ferox	Soft-shell turtle	3
Chelodina longicollis	Australian long-neck terrapin	4
Chelydra osceola	Florida snapping turtle	1
Chelydra rossignonii	Rossignon's snapping turtle	1
Chelydra serpentina	Snapping turtle	7
Chelys fimbriata	Matamata turtle	1
Chrysemys picta	Painted turtle	8
Clemmys guttata	Spotted turtle	8
Clemmys insculpta	Wood turtle	5
Clemmys marmorata	Western spotted turtle	1
Clemmys muhlenbergii	Muhlenberg's turtle	1
Cuora amboinensis	Common Malayan box-tortoise	2
Deirochelys reticularia	Chicken turtle	1
Emys blandingii	Blanding's turtle	4
Emys orbicularis	European pond turtle	11
Geomyda spengleri	Liu-kiu terrapin	1
Gopherus agassizii	Agassiz's tortoise	1
Gopherus polyphemus	Gopher turtle	4
Hydromedusa tectifera	South American snake-neck turtle	2
Kinosternon flavescens	Texas musk turtle	1
Kinosternon subrubrum	Musk turtle	4
Macrochelys temminckii	Alligator snapping turtle	1
Malaclemys centrata×M. pileata	Diamond-back terrapin (hybrids)	8
Pelomedusa galeata	Common African water tortoise	8
Pelusios heinrothi	Heinroth's turtle	2
Pelusios nigricans	Black water tortoise	1
Pseudemys elegans	Cumberland terrapin	3
Pseudemys floridana	Florida cooter	12
Pseudemys palustris	West Indian turtle	2
Sternotherus odoratus	Musk turtle	2
Terrapene carolina	Box tortoise	32
Terrapene major	Florida box turtle	11
Terrapene ornata	Ornate turtle	4
Testudo calcarata	Abyssinian tortoise	1
Testudo ephippium	Duncan Island tortoise	7
Testudo porteri	Indefatigable Island tortoise	1
Testudo radiata	Radiated tortoise	2
Testudo tabulata	South American tortoise	9
Testudo vicina	Albemarle Island tortoise	2

CROCODILIA

Alligator mississipiensis	Alligator	42
Caiman nigra	Caiman	2
Crocodylus acutus	American crocodile	2
Crocodylus cataphractus	West African crocodile	3
Tomistoma schlegeli	Malayan gavial	3

LACERTILIA

Tarentola mauretanica	Mauretanian gecko	3
Ameiva abbotti	Abbott's swift	5
Amphibolurus barbatus	Bearded lizard	3
Anolis allogus	Cuban anolis	4
Anolis carolinensis	Carolina anolis	7
Anolis equestris	Chameleon anolis	8
Anolis lineatopus	Jamaican anolis	1
Basiliscus vittatus	Banded basilisk	6
Chamaeleon senegalensis	Senegal chameleon	3
Cnemidophorus sexlineatus sacki	Spotted race-runner	2
Cnemidophorus tessellatus tessellatus	Desert whiptail	1
Coleonyx brevis	Coleonyx	1
Conolophus subcristatus	Galapagos iguana	1
Crotaphytus collaris	Collared lizard	9
Ctenosaura acanthura	Spiny-tailed iguana	5
Cyclura	iguana	1
Cyclura cornuta	Rhinoceros iguana	2
Cyclura macleayi	Cuban ground iguana	2
Cyclura nuchalis	Fortune Island iguana	3
Dipso-saurus dorsalis	Spotted lizard	2
Egernia cunninghami	Australian or Cunningham's skink	1
Gerrhonotus scincicauda webbii	Alligator lizard	1
Heloderma horridum	Beaded lizard	2
Heloderma suspectum	Gila monster	6
Hydrosaurus pustulosus	Philippine water-dragon	2
Iguana iguana	Common iguana	12
Lacerta lepida	Ocellated lizard	2
Lacerta lilfordi grossae	Balearic Island lizard	6
Lacerta lilfordi jordansi	Balearic Island lizard	7
Laemanctus alticoronatus	Green basilisk	1
Leiocephalus carinatus	Carinated curl-tail lizard	1
Leiocephalus cubensis	Cuban curl-tail lizard	2
Liocephalus beatanus	Beata curl-tail lizard	3
Ophisaurus ventralis	Glass snake	3
Phrynosoma blainvillii blainvillii	Blainville's horned lizard	1
Phrynosoma cornutum	Horned lizard	9
Phrynosoma platyrhinos	Smooth horned lizard	3
Phrynosoma m'callii	MacCall's horned lizard	1
Physignathus lesueurii	Lesueur's water dragon	1
Sauromalus obesus	Chuckwalla	1
Sceloporus clarkii	Spiny swift	3
Sceloporus undulatus	Common fence lizard	12
Tiliqua nigrolutea	Mottled lizard	1
Tiliqua scincoides	Blue-tongued lizard	3
Trachysaurus rugosus	Stump-tailed lizard	4
Tupinambis nigropunctatus	Tegu lizard	2
Uromastix spinipes	Spiny-tailed lizard	2
Varanus gouldii	Gould's monitor	2
Varanus niloticus	Nile monitor	4

OPHIDIA

Agkistrodon mokasen	Copperhead	9
Agkistrodon piscivorus	Water moccasin	5
Arizona elegans occidentalis	Faded snake	1
Carphophis vermis	Worm snake	1
Cemophora coccinea	Scarlet snake	1
Coluber constrictor constrictor	Black snake	2
Coluber dahlii	Dahls whip snake	2
Coluber hippocrepis	Horseshoe whip snake	3
Coluber jugularis caspius	European whip snake	4
Coluber longissimus	Aesculapian snake	1
Coluber quatuorlineatus	European 4-lined snake	2
Coluber quatuorlineatus sauromates	European 4-lined snake	2
Constrictor constrictor	Boa	3
Constrictor imperator	Central American or emperor boa	3
Crotalus adamanteus	Florida diamond-back rattlesnake	2
Crotalus atrox	Desert diamond-back rattlesnake	6
Crotalus cerastes	Sidewinder rattlesnake	6
Crotalus horridus	Banded rattlesnake	10
Crotalus mitchellii	Bleached rattlesnake	2
Crotalus oreganus	Pacific rattlesnake	2
Crotalus ruber	Red rattlesnake	2
Crotalus terrificus	South American rattlesnake	2
Diadophis punctatus	Ring-necked snake	3
Drymarchon corais cooperi	Indigo snake	8
Elaphe guttata	Corn snake	2
Elaphe laeta	Emory's snake	2
Elaphe obsoleta lindheimeri	Lindheimer's snake	5
Elaphe obsoleta obsoleta	Pilot snake	1
Elaphe quadrivittata	Chicken snake	5
Elaphe rosacea	Key rat snake	1
Elaphe vulpina	Fox snake	2
Epicrates angulifer	Cuban tree boa	4
Eryx johni	Sand boa	1
Eunectes murinus	Anaconda	1
Farancia abacura	Horn snake	2
Heterodon contortrix	Hog-nose snake	1
Lampropeltis californiæ	California king snake	1
Lampropeltis calligaster	Yellow-bellied king snake	1
Lampropeltis getulus getulus	King snake	3
Lampropeltis getulus boylii	Boyle's king snake	1
Lampropeltis rhombomaculata	Mole snake	2
Lampropeltis triangulum	Milk snake	1
Lejosophis gigas	Cobra de Paraguay	2
Leptophis occidentalis	Green tree snake	1
Lichanura roseofusca	California boa	1
Liodytes alleni	Allen's mud snake	1
Loxocemus bicolor	American python	2
Masticophis flagellum flavigularis	Coachwhip snake	9
Masticophis flagellum frenatus	Red racer	1

Masticophis lateralis	California racer	1
Micrurus fulvius	Coral snake	1
Naja hannah	King cobra	1
Natrix fasciata fasciata	Banded water snake	2
Natrix grahamii	Graham's water snake	1
Natrix natrix	European grass snake	3
Natrix	Water snake	24
Natrix	Red water snake	1
Opheodrys aestivus	Rough-scaled green snake	1
Pituophis catenifer annectens	California bullsnake	7
Pituophis sayi	Bullsnake	4
Python molurus	Indian python	3
Python regius	Ball python	3
Python reticulatus	Regal python	2
Python sebae	African python	3
Python variegatus	Carpet python	1
Sistrurus miliarius	Pigmy rattlesnake	1
Sonora occipitalis	Tricolored ground snake	1
Thamnophis sauritus proximus	Western ribbon snake	1
Thamnophis sauritus sauritus	Ribbon snake	3
Thamnophis sirtalis sirtalis	Garter snake	3
Tretanorhinus variabilis	Cuban water snake	2

Amphibians

CAUDATA

Ambystoma mexicanum	Axolotl	2
Amphiuma tridactylum	Congo eel or Congo snake	3
Cryptobranchus alleganiensis	Hellbender	5
Megalobatrachus japonicus	Giant salamander	2
Pleurodeles waltlii	Spanish newt	2
Proteus anguinus	Blind salamander	4
Pseudobranchus striatus	Striped mud eel	2
Salamandra salamandra	European spotted salamander	2
Triturus pyrrhogaster	Red-bellied Japanese newt	3
Triturus viridescens	Common newt	5

SALIENTIA

Alytes obstetricans	Midwife toad	2
Bufo alvarius	Green toad	7
Bufo americanus	Common American toad	2
Bufo fowleri	Fowler's toad	3
Bufo marinus	Marine toad	1
Bufo peltocephalus	Cuban giant toad	5
Bufo terrestris	Southern toad	4
Bufo valliceps	Mexican toad	3
Hyla cinerea	Green tree frog	5
Hyla gratiosa	Florida tree frog	4
Hyla baudinii	Mexican tree frog	1
Hyla septentrionalis	West Indian tree frog	1
Hyla versicolor	Common tree frog	1
Leptodactylus pentadactylus	Dominican giant frog	4
Rana catesbeiana	Bull frog	1

Summary

Animals on hand July 1, 1930	1,996
Accessions during the year	1,266
Total animals in collection during year	3,262
Removed from collection by death, exchange, and return of animals on deposit	761
	2,501

Status of collection

	Species	Individuals
Mammals	189	563
Birds	333	1,076
Reptiles	164	606
Amphibians	31	94
Fishes	14	47
Arachnids	4	11
Insects (colony)	1	1
Crustaceans	1	75
Mollusks	4	28
Total	741	2,501

ANIMALS NOT PREVIOUSLY EXHIBITED

This year has been outstanding in the number of species exhibited for the first time in the National Zoological Park. These are:

MAMMALS

Babirussa alfurus	Babirussa.
Cercopithecus petronellae	White-crowned guenon.
Dolichotis salinicola	Dwarf cavy.
Hylobates cinereus	Bornean gray gibbon.
Leontocebus rosalia	Silky or lion-headed marmosette.
Nyctereutes procyonoides	Raccoon dog.
Symphalangus syndactylus	Siamang gibbon.

BIRDS

Aprosmictus cyanopyzicus	Australian king parrot.
Crossoptilon mantchuricum	Brown-eared pheasant.
Goura sclateri	Sclater's crowned pigeon.
Lephophorus impeyanus	Himalayan Impeyan pheasant.
Polyplectron napoleonis	Palawan peacock-pheasant.
Priotelus temnurus	Cuban trogon.
Phasianus versicolor	Green Japanese pheasant.
Riccordia ricordii	Ricord's humming bird.
Trichoglossus novaehollandae	Blue-bellied lory.

REPTILES

Agkistrodon bilineatus	Mexican moccasin.
Ameiva abbotti	Abbott's swift.
Amphibolus barbatus	Bearded lizard.
Anolis equestris	Chameleon anolis.
Bitis arietans	Puff adder.

Rana clamitans	Green frog	8
Rana palustris	Common swamp frog	2
Rana sphenocephala	Southern leopard frog	3
Rana esculenta	Edible frog	5
Rana dalmatina	Agile frog	1
Xenopus mulleri	East African smooth-clawed frog	1

Fishes

Aequidens sp		1
Barbus ocellifer		2
Brachydanio rerio	Zebra fish	1
Colius lala	Dwarf gourami	4
Enneacanthus gloriosus	Sunfish	1
Fundulus sp	Killifish	1
Lebistes reticulatus	Guppy	12
Asteonyx ruberrinus	Red tail	7
Pterophyllum scalare	Angel fish	3
Rasbora heteramorpha		3
Rhinichthys atronasus	Striped dace	7
Rivulus harti	Trinidad fish	1
Xiphorus helleri	Swordtail	2

Arachnids

Eurypelma sp	Tarantula	1
Hadrurus hirsutus	Giant hairy scorpion	8

Insects

Apis mellifica	Honey bees	1 colony

Crustaceans

Cenobita clypeatus	Hermit crabs	75

Mollusks

Achatina variegata	Giant land snail	1
Ampularia sp	Apple snail	1
Liguus fasciatus	Florida tree snail	1
Planorbis corneus	Red snail or rams horn	25

Statement of the collection

Accessions

	Presented	Born	Received in exchange	Purchased	On deposit	Total
Mammals	81	60		21	6	168
Birds	288	14	4	29	14	349
Reptiles	268		3	178	2	451
Amphibians	90			40		130
Fishes	4					4
Arachnids	12					12
Insects [1]						1
Crustaceans	123					123
Mollusks	27			1		28
Total	894	74	7	269	22	1,266

[1] 1 colony.

Bitis gabonica	Gaboon viper.
Bitis nasicornis	Rhinoceros viper.
Bothrops nigroviridis marchi	Green tree viper.
Bothrops nummifera	Jumping viper.
Chamaeleon senegalensis	Senegal chameleon.
Coluber jugularis caspius	European whipsnake.
Coluber leopardinus	Leopard snake.
Coluber longissimus	Aesculapian snake.
Coluber quatuorlineatus	European 4-lined snake.
Geomyda incisa	Guatemalan terrapin.
Laemanctus alticoronatus	Green basilisk.
Lampropeltis polyzonus	Tropical king or false coral snake.
Lejosophis gigas	Cobra de Paraguay.
Liocephalus beatanus	Beata curl-tailed lizard.
Loxocemus bicolor	American python.
Mabuya agilis	Guatemalan skink.
Naja hannah	King cobra.
Naja tripudans	Hooded cobra.
Oxybelis acuminatus	Pike-headed tree snake.
Pelusios heinrothi	Heinroth's turtle.
Tomistoma schlegeli	Malayan gavial.
Tretanorhinus variabilis	Cuban water snake.

AMPHIBIANS

Alytes obstetricans	Midwife toad.
Ambystoma mexicanum	Axolotl.
Bufo valiceps	Mexican toad.
Pleurodeles waltlii	Spanish newt.
Proteus anguinus	Blind salamander.

FISHES

Aequidens sp.	
Barbus ocellifer.	
Brachydanio rerio	Zebra fish.
Colius lala	Dwarf gourami.
Enneacanthus gloriosus	Sunfish.
Fundulus sp	Killifish.
Lebistes reticulatus	Guppy.
Asteonyx ruberrinus	Red tail.
Pterophyllum scalare	Angel fish.
Rasbora heteramorpha	Rasbora.
Rhinichthys atronasus	Striped dace.
Rivulus harti	Trinidad fish.
Xiphorus helleri	Swordtail.

ARACHNIDS

Hadrurus hirsutus	Giant hairy scorpion.

INSECTS

Apis mellifica	Honey bees	1 colony.

This excellent showing was made possible primarily by the exhibition facilities afforded in the new reptile house.

VISITORS

The great number of visitors who have been coming to the park since the opening of the reptile house has prevented such a decline in the year's attendance as exists in other institutions of public interest because of the economic depression which has so reduced travel. The estimated attendance as recorded in the daily reports of the park is as follows:

1930		1931	
July	186, 600	January	97, 600
August	170, 000	February	82, 948
September	221, 710	March	315, 750
October	130, 200	April	377, 207
November	105, 000	May	228, 500
December	36, 000	June	220, 000
		Total visitors for year	2, 171, 515

The attendance of organizations, mainly classes of students, of which we have definite record, was 34,026 from 649 different schools in 21 States and the District of Columbia, as follows:

States	Number persons	Number parties	States	Number persons	Number parties
Alabama	30	1	New Jersey	2, 972	49
Connecticut	192	2	New York	2, 946	30
Delaware	124	6	North Carolina	387	11
District of Columbia	11, 305	234	Ohio	1, 046	13
Iowa	29	1	Pennsylvania	7, 204	152
Illinois	76	1	Tennessee	75	2
Indiana	50	1	Virginia	1, 158	28
Kansas	326	1	West Virginia	161	5
Maine	74	1	Wisconsin	150	2
Maryland	5, 548	104			
Massachusetts	94	3		34, 026	649
Michigan	79	2			

Observations of the numbers of automobiles from distant States and countries has led to the taking of a census each day of the cars actually parked in the park at one time, from which the following tabulation has been prepared showing the percentages of cars from various States and countries by months:

State	Percentage, March	Percentage, April	Percentage, May	Percentage, June
Alabama		0. 02		0. 19
Arizona		. 04		
California	0. 06	. 13	0. 29	. 16
Colorado				. 06
Connecticut	. 16	. 37	. 26	. 08
Delaware	. 05	. 33	. 02	. 25
District of Columbia	73	53	54	52. 41
Florida	. 14	. 24	. 38	. 55
Georgia	. 05	. 07	. 14	. 25
Illinois	. 07	. 24	. 12	. 45

State	Percentage, March	Percentage, April	Percentage, May	Percentage, June
Indiana	0.10	0.07	0.17	0.46
Iowa	.03	.02	.06	.19
Kansas			.10	.08
Kentucky	.07	.02	.12	.27
Louisiana		.02		
Maine	.05	.09	.05	.03
Maryland	15.75	20.35	24.65	20.47
Massachusetts	.40	.96	.48	.46
Michigan	.15	.33	.19	.54
Minnesota	.10	.15	.02	.27
Mississippi	.05	.02		.08
Missouri	.05	.13		.20
Montana	.03			
Nebraska			.02	.11
New Hampshire	.05	.09		.14
New Jersey	1	2.54	.62	.62
New Mexico	.10		.05	
New York	1	2.10	.17	1.27
North Carolina	.26	.55	.94	1.65
North Dakota	.12	.04		.06
Ohio	.39	.72	1.16	1.75
Oklahoma	.03	.02	.05	.06
Oregon		.02		.03
Pennsylvania	.95	5.48	3.48	4.25
Rhode Island	.12	.20	.10	.06
South Carolina	.05	.02	.14	.24
South Dakota	.03		.03	.03
Tennessee	.03	.09	.17	.19
Texas	.07	.02	.05	.11
Vermont	.17	.07		
Virginia	4	10.77	11.20	10.40
Washington	1		.05	.03
West Virginia	.12	.51	.60	1.20
Wisconsin	.05	.09	.10	.03
Wyoming			.02	.03
Alaska				.06
Canada	.15	.07		.14
Cuba				.03
Canal Zone				.03
Philippine Islands				.03

IMPROVEMENTS

The most interesting event of recent years has been the opening of the public exhibition building for reptiles, amphibians, insects, and miscellaneous invertebrates. The construction of this building was started in March, 1930, and the exhibition was formally opened the evening of February 27, 1931. Some 3,000 people attended the reception, and the following day the building was crowded from morning to night. The formal opening was attended by a large number of officials of the United States Government and officials of other zoos who were particularly interested in the building. Among the latter were Dr. W. Reid Blair, director of the New York Zoological Park; C. Emerson Brown, director of the Philadelphia Zoological Garden; George P. Vierheller, director of the St. Louis Zoological Garden; Dan Harkins, director of Franklin Park Zoo, Boston; and Dr. Raymond L. Ditmars, curator of reptiles, New York Zoological Park.

Since its opening it has been by far the most popular and crowded building in the entire Zoo. Natural habitat for the reptiles has been provided as far as possible. There is a special ventilating sys-

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tem for the public and a special heating system for the reptiles. Light is all from above so that the visibility is far superior to anything we have ever had before. This building, containing over a hundred cages, fills a long felt need in the Zoo.

With a view to helping house the Victor J. Evans collection, Congress added $4,500 to the appropriation, and with this money we have built a series of large mammal paddocks with sheds, runs for cranes, and large outdoor cages for pheasants.

Out of money unexpended from a previous year and reappropriated for this fiscal year is being built a flight cage for the eagles, to replace the one that had to be torn down to clear the site for the reptile house. Other cages will be constructed near by, so that all of the birds will be grouped in the general vicinity of the bird house.

Contracts have been let for new boilers at the central heating plant, to replace two secondhand ones that had been installed 29 years ago. The main steam line from the central heating plant to the buildings began to give way during the early fall, and certain of the steam lines supplying individual buildings began to develop leaks, which indicated that they could no longer be successfully repaired. This matter was presented to Congress, with the result that sufficient money was provided to renew the lines that showed most imminent danger of giving out. The new pipes are planned to be a portion of an extensive central conduit system when finally completed.

A quantity of earth from near-by excavations was made available to the park without cost, and, by carefully planning the dumping of this, three considerable level areas were developed on which we are now able to place outside paddocks, runs, and cages.

NEEDS OF THE ZOO

Since completion of the reptile house, the next building on our program, the small mammal and great ape house, becomes the one most urgently needed at the present time. We have no suitable quarters at all for these groups of animals, both of which are represented in the collection by continually increasing numbers of interesting species. Plans and specifications for this building are now being prepared under the appropriation of $4,500 made available by the last Congress for this purpose.

Following this, the next exhibition building needed is one for the pachyderms. A room to complete the bird house is also needed.

Respectfully submitted.

W. M. Mann, *Director.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1931:

PLANT AND OBJECTS

This observatory operates regularly the central station at Washington and two field stations for observing solar radiation on Table Mountain, Calif., and Mount Montezuma, Chile. The station at Mount Brukkaros, Southwest Africa, which was established by the National Geographic Society, is being continued for the present in cooperation with the Astrophysical Observatory with funds donated by a friend of the Institution. In addition the observatory controls a station on Mount Wilson, Calif., where occasional expeditions are sent for special investigations.

The principal aim of the observatory is the exact measurement of the intensity of the radiation of the sun as it is at mean solar distance outside the earth's atmosphere. This is ordinarily called the solar constant of radiation, but the observations of past years by this observatory have proved it variable. As all life, as well as the weather, depends on solar radiation, the observatory has undertaken the continued measurement of solar variation on all available days. These measurements have now continued all the year round for 12 years. As will appear in this report, recent studies indicate that the permanent continuation of these daily solar-radiation measurements may have great value for weather forecasting. In addition to this principal object the observatory undertakes spectroscopic researches on radiation and absorption of atmospheric constituents, radiation of special substances, such as water vapor, ozone, carbonic-acid gas, liquid water, and others, and the radiation of the other stars as well as of the sun.

WORK AT WASHINGTON

Funds having been appropriated by the Congress to print Volume V of the Annals of the Astrophysical Observatory, the year was spent principally in preparing text, tables, and illustrations expressing the results of observations made since August, 1920, at the several stations.

As stated in previous reports, much effort had already been expended in reducing the observations made at Table Mountain, Calif., but without satisfactory results. The atmosphere above Table Mountain, though to the eye appearing very fine and clear, contains variable amounts of ozone, water vapor, and dust, which produce embarrassing difficulties in computing the solar constant of radiation. Daily measurements of the amount of atmospheric ozone by the method of Dobson had been in progress at Table Mountain, since August, 1928, but they require fully as much time for reduction as does the solar constant itself. Fortunately, as described in last year's report, we were able to devise a simple method based on our bolographic work whereby corrections can be made easily for the absorption of ozone on all days when solar-constant measures are made at Table Mountain. All the Table Mountain solar-constant values from the beginning there in 1925 have now been corrected for ozone absorption.

The changes of haziness and of absorption associated with variations of atmospheric water vapor make a difficulty of a more serious nature. After several unsuccessful attempts to vary the Montezuma procedure to suit Table Mountain conditions, the process of reduction of the short-method solar-constant determinations at Table Mountain was radically changed. It will be recalled that the essence of the short method consists in employing pyranometer measurements of the brightness of the sky near the sun as an index of the prevailing atmospheric transparency.

If the brightness of the sky were unaffected by varying quantities of smoke or dust, we should expect the normal change of its brightness from day to day to be exactly determined by the quantity of atmospheric water vapor prevailing. In other words, there would be a normal relation between pyranometry, precipitable atmospheric water vapor, and atmospheric transparency, for the different wave lengths. But if unusual degrees of dustiness or smokiness prevail, then the pyranometer will record a positive or negative excess from the normal value proper to the prevailing quantity of precipitable water. This "excess" will be associated with changes in the atmospheric transmission coefficients for all wave lengths.

On these lines we have worked out new varieties of the short method of determining the solar constant of radiation applicable to conditions at Table Mountain and Mount Brukkaros. We have reduced all the observations made at these stations according to these new methods. Great improvement in their solar-constant determinations resulted, although it must be confessed that neither of these two stations yields results as generally satisfactory as does Montezuma.

COMPARISON OF RESULTS

With the completion of the reduction of all the solar-constant observations from the three field stations results of much interest are found by comparing them. Figure 1 shows the monthly mean solar-constant values derived from Table Mountain, Montezuma, and Mount Brukkaros since 1926. The probable error of the weighted mean curve shown as a heavy line in Figure 1 is less than 0.1 per cent. In short, it is adequately accurate to show all that needs be known of the general march of solar variation.

Figure 2 shows the preferred monthly mean solar-constant values from 1920 to 1930, inclusive. The extreme range of it is 2.8 per cent. Although apparently so irregular, Figure 3 shows that the march of solar variation may be expressed with surprising fidelity as the sum of five regular periodicities, of 68, 45, 25, 11, and 8 months' intervals. It is interesting to note that, though derived with no regard to it, all of these intervals turn out to be nearly related to the 11¼-year sun-spot period. Thus 68 months is its half, 45 months its third, and so on. Other periods are found which are not so long-lived as these. Thus, curve H in Figure 3 shows periods of 45 and 5.6 days, respectively, which lasted throughout the year 1924. The excellent representation of the original curve A by the sum of the five periodicities, as shown at B, encourages me to give in curve I the expected march of solar variation in 1931 and 1932.

Figure 4 gives the results of an attempt to represent the temperatures of Washington, D. C., and Williston, N. Dak., as made up of periodicities having these same five intervals, 68, 45, 25, 11, and 8 months. It proved necessary to add a period of 18 months in each case. The original temperature curves A and C are found by taking consecutive means of 5-month departures from normal. Thus, 1/5 (Jan.+Feb.+Mar.+Apr.+May): 1/5 (Feb.+Mar.+Apr.+May+June), and so on. This eliminates the shorter irregularities and brings out prominently the principal departures from normal temperature that have occurred since 1918.

Curves B and D are 5-month consecutive means of curves representing the observed march of temperature as the sum of the six periodicities above described. I do not insist that this method of treatment gives certainty as yet, but I look forward for five more years to 1936, when it can be subjected to a more rigorous test. Time will show whether or not it is the germ of the method of forecasting weather for future years, to which Langley looked forward when he founded the Astrophysical Observatory.

The comparison of stations shows that the *daily* solar-constant values are not as accurate as are needed. Montezuma results are by far the best. Yet they lack many days of completeness and many

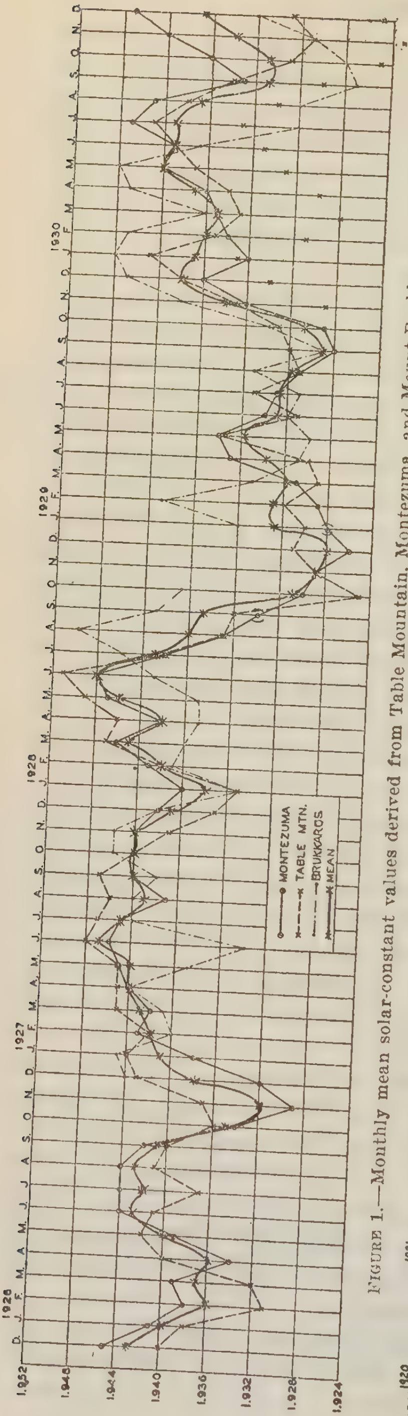


FIGURE 1.—Monthly mean solar-constant values derived from Table Mountain, Montezuma, and Mount Brukkaros since 1926

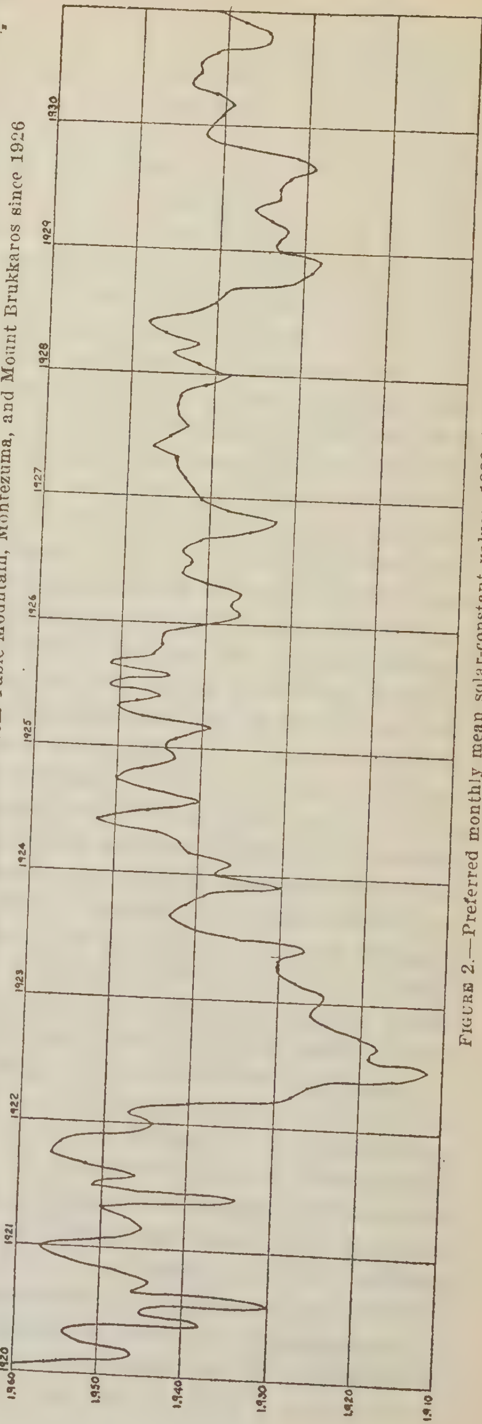


FIGURE 2.—Preferred monthly mean solar-constant values, 1920–1930

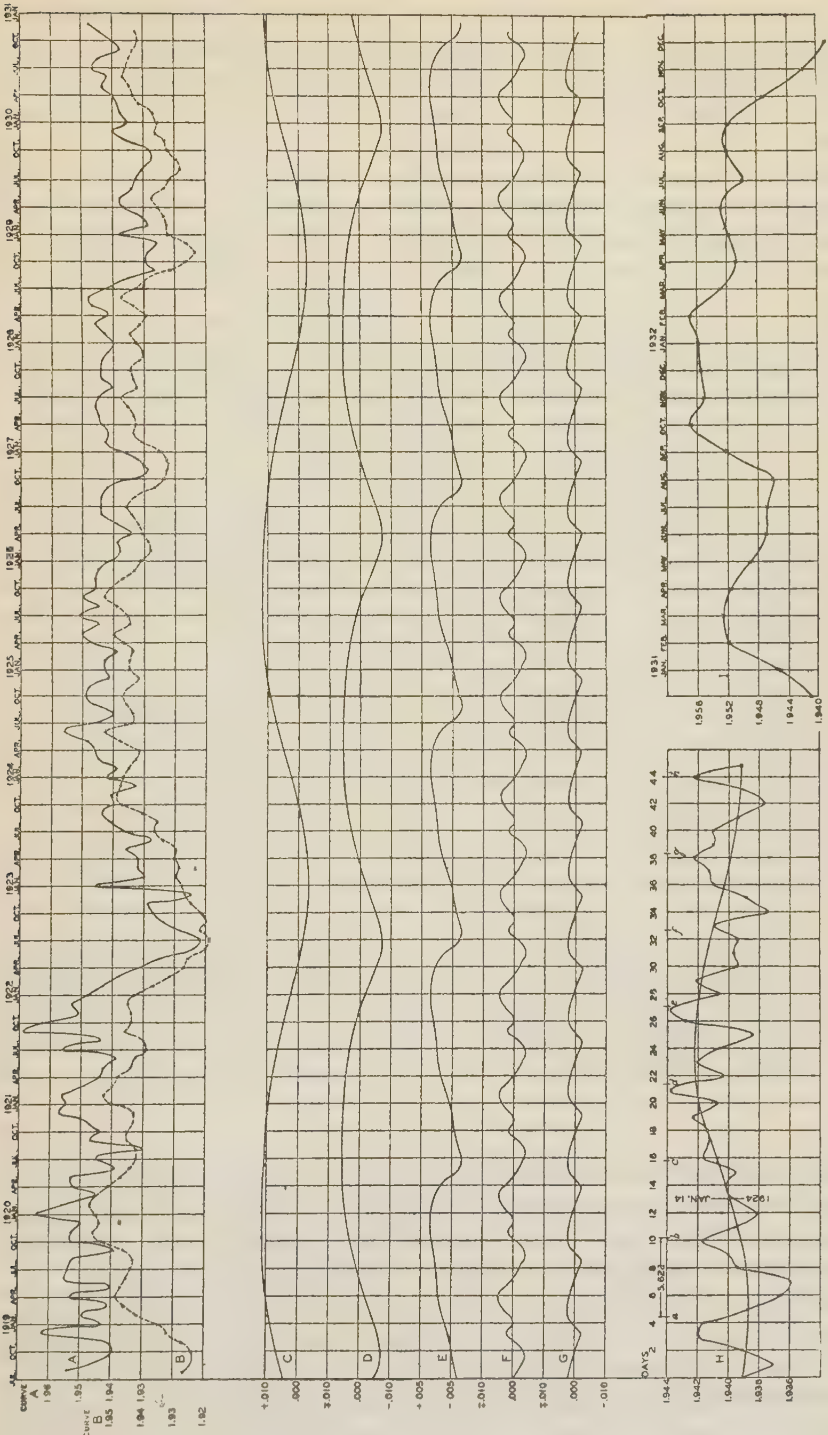


FIGURE 3.—Solar variation represented by five regular periodicities

days represented are unsatisfactory. It is indeed almost beyond the limit of possible accuracy to observe the solar constant day after day with such exactness that the differences between the absolute values shall always evaluate changes correctly if reaching one-third of 1 per cent or more. This is what is needed. We have in mind a few improvements which may bring us to this degree of accuracy at Montezuma, but unless other stations superior to Table Mountain and Brukkaros are found it seems doubtful if fully satisfactory daily values are obtainable to supplement the Montezuma record.

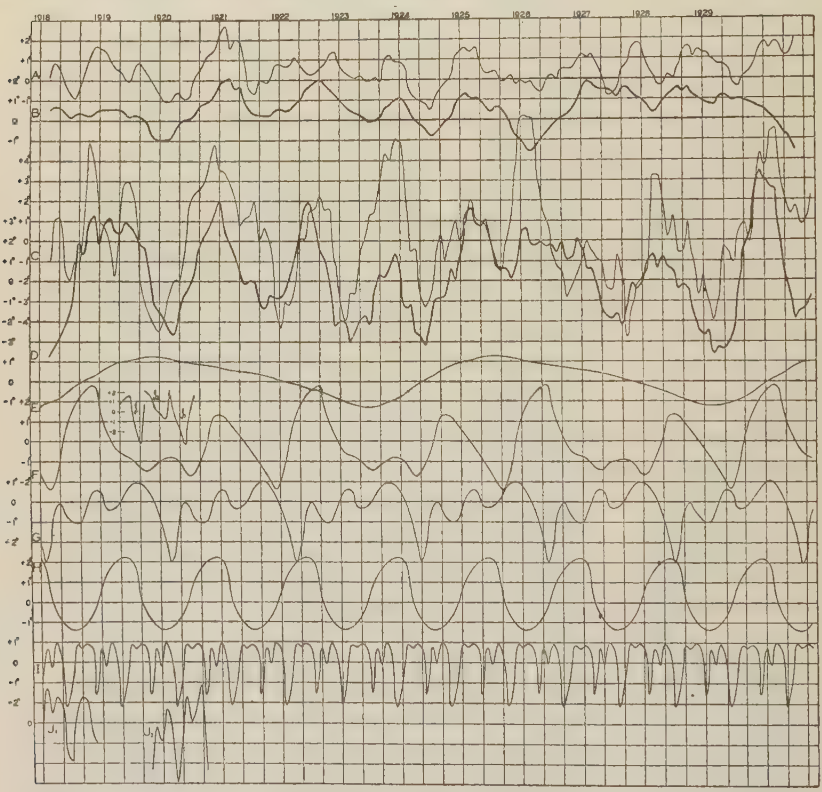


FIGURE 4.—Washington and Williston temperatures associated with solar periodicities. Five-month consecutive means

Further studies made during the year tend to confirm the impression stated in last year's report that temperatures and barometric pressures in the United States respond by opposite trends to positive and negative sequences of change in daily solar-radiation values. As yet, however, the evidence is not fully satisfactory owing to the imperfection of the daily record of solar changes, as just explained.

To promote statistical studies along these lines, a new instrument designed to discover and evaluate periodicities in solar and weather records has been designed. Its construction was aided by a grant of

$1,000 from the Research Corporation of New York. At the close of the fiscal year the instrument was almost ready for use, having been constructed by A. Kramer at the instrument shop of the Observatory.

FIELD STATIONS

In cooperation with Doctor Wulf, of the Fixed Nitrogen Research Laboratory, of the Department of Agriculture, an investigation has been carried through at Table Mountain, Calif., on the absorption of well-determined quantities of ozone in the visible spectrum. In this research, ozone-laden air contained in special absorption cells was interposed before the slit of the spectrobolometer which records the energy of the solar spectrum. A new, independent method of determining the atmospheric ozone content was worked out and applied. Its results agree nearly with those determined by the method of Dobson.

The daily observation of the solar constant of radiation has been carried on regularly at the three field stations: Table Mountain, Calif.; Montezuma, Chile; and Mount Brukkaros, Southwest Africa. The latter station has been supported by grants from John A. Roebling. Impressed by the probability of useful weather applications, Mr. Roebling has made a further grant to finance an expedition of a year's duration in Africa and outlying regions to endeavor to find a site equal to Montezuma, Chile, for solar-radiation work. Accompanied by Mrs. Moore, A. F. Moore, who has had long experience at our mountain observatories, occupied Fogo Island peak in the Cape Verde Islands for several weeks, and is now in Southwest Africa testing various high mountain sites in comparison with Mount Brukkaros.

A fire caused by a kerosene heater destroyed the computing room at Montezuma station, with mathematical tables and instruments used in the reductions. The observations suffered a few days of delay before new tables could be sent, but no days were lost to the permanent record of the station.

PERSONNEL

At Washington the personnel is unchanged since the last report, except that Oliver Grant served as additional computer throughout the year in the preparation of Volume V of the Annals. Also George Cox served from November, 1930, on the reduction of ozone observations and other computing. Both young men were compensated from the Roebling funds.

C. P. Butler, formerly assistant at Montezuma, was placed in charge of that station on January 11, 1931, vice H. H. Zodtner, transferred to Table Mountain to carry on there during the absence of

A. F. Moore. Walter Watson, jr., reported for duty as assistant at Montezuma February 1, 1931.

SUMMARY

The principal work accomplished has been the development of new methods and the complete reduction of all solar-constant observations made at the field stations since 1920. The results with accompanying text and illustrations have been collected and sent to press as Volume V of the Annals of the Observatory. Comparison of values shows that the variation of the sun indicated by monthly mean values since 1920 is determined with sufficient accuracy for all purposes. The probable error of monthly means is less than 0.1 per cent. Solar changes found since 1920 range to 2.8 per cent. Daily observations are less satisfactory than monthly means, but improvements are proposed. An expedition is in Southwest Africa endeavoring to discover a site for a solar radiation observatory equal to Montezuma, Chile. A new instrument for the periodic analysis of solar and weather data is nearly completed.

On the whole the outcome of 10 years of intensive study of solar radiation, as brought together in the text of Volume V of the Annals of the Observatory now in press, is very interesting. It encourages great hope that the causes of weather may be traced in solar variation to such a degree as to enable the skilled meteorologist to forecast principal changes of weather far in advance.

Respectfully submitted.

C. G. Abbot, *Director.*

The Secretary,
Smithsonian Institution.

APPENDIX 8

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

Sir: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during its second year ending June 30, 1931.

RESEARCH IN PROGRESS

Building around the central idea of a laboratory combining experimental work in biophysics with fundamental experimentation in physics and chemistry, researches have been carried forward in both these fields. The phototropic experiments upon oat coleoptiles previously reported have been carried further with considerable refinement of technique. The carbon dioxide assimilation of wheat has been studied as a function of intensity in artificial light. Preliminary experiments with algae have been initiated with a view to determining carbon dioxide assimilation as a function of wave length and intensity, growth rate as a function of wave length and intensity, and death point as a function of wave length, and time-intensity dosage. The propagating chamber which was developed by the division has been used in cooperation with the Department of Agriculture for the purpose of investigating the effects of artificial light, humidity, and temperature upon the growth of certain desert and tropical plants.

In the field of pure physics and physical chemistry the major part of the time has been devoted to the development of the necessary equipment for the general intensity and infra-red work contemplated. The intensity distribution in the mercury spectrum has been determined directly. In cooperation with the Fixed Nitrogen Research Laboratory the spectra of HCl, HCN, and the halogen substitution products of benzene have been investigated in the region between the visible and 2μ.

PHOTOTROPISM

In a preliminary experiment the phototropic response of the oat coleoptile toward light was determined comparatively for different colors or spectral regions by means of light filters. The results of this experiment may be conveniently summed up in the accompany-

ing graph, Figure 1. The spectral regions used are indicated by the transmission curves. The wave lengths are plotted as abscissae and the percentages of light transmitted by the filters as ordinates. The continuous curves indicate the regions of transmission for each of the filters; the blue filter (B) transmitting the region between 4,000 and 5,000 Å units, the green filter (G) transmitting between 4,800 and 5,900Å units, the yellow filter (Y) transmitting all visible wave lengths longer than 5,300 A, and the red filter (R) transmitting all wave lengths longer than 5,900 Å. For the sake of convenience the observable response curves have been plotted upon the same diagram in dotted lines. The response in the red was found to be zero. The response to yellow light has been arbitrarily assigned the value "unity." Using a logarithmic scale (inside the frame) the relative responses in green and blue have been indicated. In the right-hand

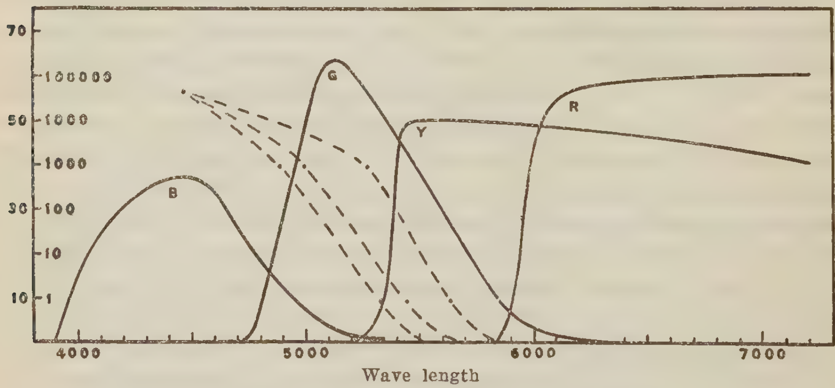


FIGURE 1.—Phototropism by filter method
---------- Phototropic sensitivity.
———— Transmission of filters.

curve each point is plotted at the wave-length center of gravity of the region for each filter, in the case of yellow, only counting those wave lengths not included by the red filter.

This curve plotted through these three points may be regarded as a first approximation. On the basis of this curve the centers of gravity were redetermined where each wave length was weighted according to responses as indicated by the first approximation curve. The middle curve was thus obtained by simply shifting the points to the weighed center of gravity wave lengths. Using this second approximation curve as the basis for again reweighting, the third or left-hand curve was obtained. Reweighting was, of course, impossible for the blue region, as data are not available on the shorter wave-length side.

These results are presented for the sake of comparison with the results obtained in the more elaborate experiment carried out with

the use of a monochromator for obtaining narrower spectral regions or purer colors. In this way more points could be secured in determining the response curve, and the amount of correction required for shift of center of gravity minimized. The results of this second experiment are shown in Figure 2. Points determined showing the relative response as a function of wave length are indicated by solid dots plotted on an arithmetic scale (inside frame). These points have again been plotted as crosses on a logarithmic scale as indicated outside the frame. The results of the earlier experiment are shown as circles.

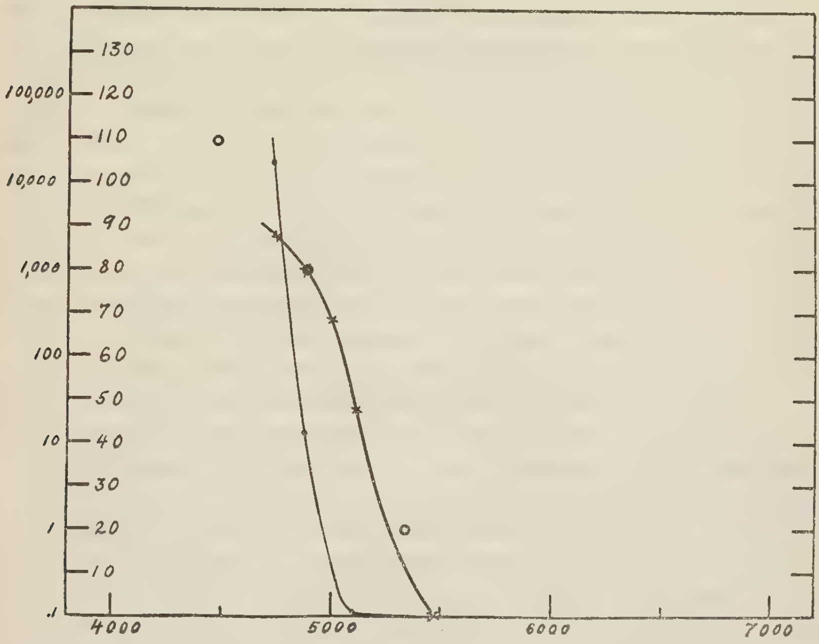


Figure 2.—Phototropism by monochromator method
—X— sensitivity on logarithmic scale (indicated outside of box)
—O— sensitivity on linear scale (indicated inside of box)

Agreement between the two experiments is quite striking considering the rough nature of the earlier experiment.

In the phototropic experiments the biological technique has been developed by Doctor Johnston and the intensity relations determined by Doctor McAlister. The demands upon physical technique were so extreme that special vacuum thermocouples had to be developed and the galvonometer deflection measured by means of a thermal relay.

It is interesting to note in this connection that Blaauw had secured similar curves for phototropic response, measuring instead of relative

intensity, the time required for the first observable response. That these curves determined by time of initial response should be almost identical to those determined by quantitative intensity ratios strongly points to a possible time-intensity product as the effective factor in controlling the phototropic response. This is particularly interesting, as such a relation is found to hold to a first approximation in the case of photographic plates on the one hand and the erythema dosage for the human skin on the other, as well as in most simple systems.

PHOTOSYNTHESIS

Special all-vitreous growth chambers have been developed wherein the carbon dioxide assimilated by wheat plants can readily be determined. The accompanying illustration (pl. 1, fig. 1) indicates the type of chamber developed; the plants are inserted through holes in the cork stopper and held in place by cotton, the roots being immersed in a nutrient solution contained in the Erlenmeyer flask; the leaves extend upward in a special tubular compartment. This tubular compartment is double walled, permitting the circulation of water for the maintenance of temperature. Illumination is secured through these lateral walls. For experimentation with the blue and ultra-violet similar containers have been made of corex. Air is conditioned by a humidifier and introduced through an air-flow regulator into the base of the leaf chamber. It is expelled at the top and a portion passed through a conductivity cell. The variation in carbon-dioxide content is thus determined by changes caused in the conductivity of a potassium hydroxide solution. The record is made continuously by a Leeds and Northrup automatic bridge.

In later experiments eight 300-watt lights mounted upon adjustable arms were substituted for those shown. Thus 2,400 watts could be placed at any distance from 20 centimeters to a meter, the illumination being lateral and strictly symmetrical. A thermocouple with a cylindrical receiver is introduced through the top in order to determine accurately the relative intensities for different adjustments. The accompanying diagram (fig. 3) shows a typical run carried out during a single day, showing the carbon dioxide assimilated for each different light intensity.

To a first approximation the curve is apparently made up of two straight-line segments. While this appears to support the classical theory of Blackman concerning limiting factors, no such conclusion should be drawn until more rigid control can be maintained. The small changes in values which may result may be sufficient to obliterate the apparent linearity.

This work differs from earlier work in that it is carried out with entire plants instead of individual leaves cut from plants as previously used. The results presented must be regarded as simply preliminary, since certain difficulties are yet to be overcome. These experiments are preparatory for those contemplated wherein approximately monochromatic light will be used. The development of equipment for this more elaborate experiment is nearing completion.

In this work Doctor Johnston has carried out the physiological phases of the experiment and Mr. Hoover has perfected the carbon dioxide recording apparatus loaned to the division by the Fixed Nitrogen Research Laboratory and has carried out the observations with this instrument.

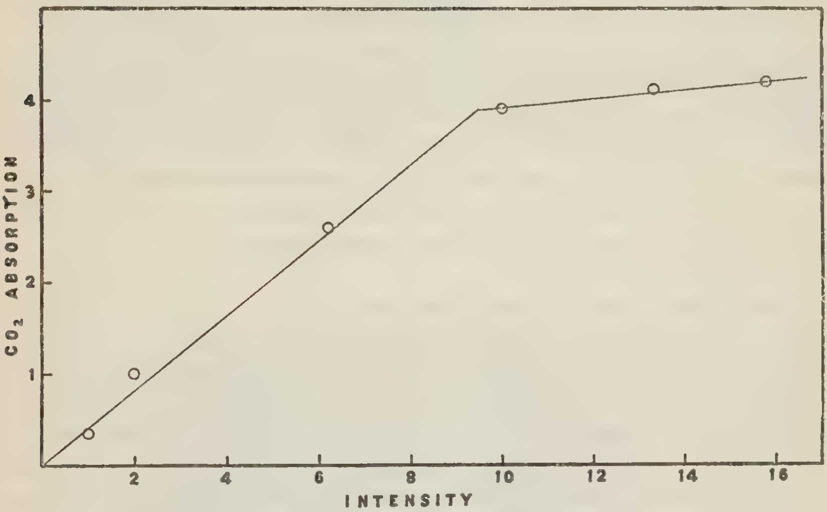


FIGURE 3.—Dependence of photosynthesis on light intensity

ALGAE INVESTIGATIONS

As a result of the cooperation of the Department of Agriculture Doctor Meier has been able to initiate a program of algae investigations which will be extended through the following year as a part of her work as National Research Council Fellow in the division. Preliminary experiments have been carried out in which the many special types of algae which she has collected have been subjected to different nutrient solutions, and to different temperature and illumination conditions, with a view to determining the conditions required for the experiments contemplated.

She has found that certain varieties may be grown in a colorless condition in the dark and subsequently gain their normal coloration

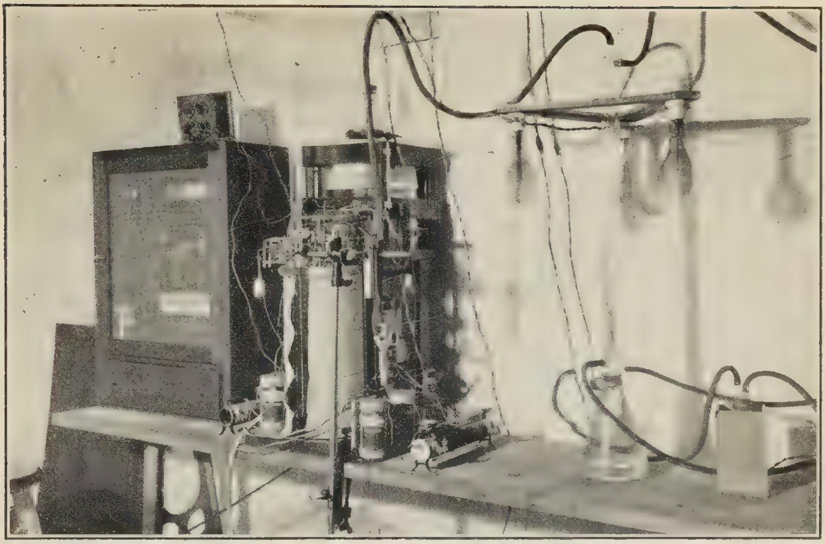
upon exposure to light. These will be used for experiments in which coloration is determined as a function of wave length and intensity.

Provision has been made for growing a large number of algae cultures under comparable conditions. For this purpose two tables have been constructed, each with four glass-bottomed reservoirs. Small Erlenmeyer flasks containing solution cultures of algae are immersed in these large water baths and illuminated by artificial light from below. A circulating system maintains each set of four reservoirs at the same temperature. The small Erlenmeyer flasks containing the algae are maintained in agitation by a common driving mechanism. Only the illumination is different in one reservoir from that in another. Thus the effect of modifying wave length or intensity may be determined for 18 different samples at once. The flasks may be supplied with small manometers in order to make a rough check on the photosynthetic processes as they are affected by growth and modification of conditions of illumination. All this work, however, is simply an auxiliary to the more careful experiment to be carried out intensively in a modified Warburg apparatus wherein differential nephelometric measurements are made as well as the usual manometric measurements upon oxygen concentration. The apparatus for these more refined measurements is in process of construction.

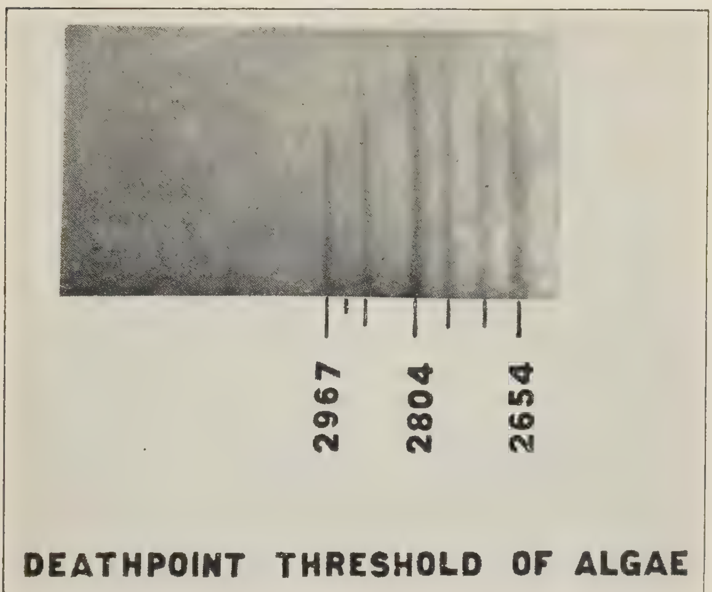
A large quartz spectrograph has been constructed, using two quartz prisms some 15 cm on a side with quartz lenses of a 60 cm focal length. By means of the spectrograph unicellular organisms distributed uniformly on a slide or in a culture dish may be exposed simultaneously to different regions of the spectrum. Modifications in growth rate or resulting death point may be observed comparatively for different wave lengths. In Plate 1, Figure 2, the results of a preliminary exposure of algae are readily observed. For all wave lengths shorter than 3,000 Å the typical mercury lines appear just as they would be seen on a photographic plate. Here, however, they are recorded by the absence of the organisms after a week's growth subsequent to exposure. It should be noted that although the lines on the long-wave length side of 3,000 Å are stronger by actual thermocouple determination they have not affected the algae colony.

For convenience, Figure 5 may be referred to in this connection, which shows the relative intensities of the different lines of the mercury arc as determined in an experiment to be discussed later in another connection.

By a succession of such experiments, wherein the first noticeable killing can be determined for different exposure times, the relative dosage of different wave lengths can be determined.



1. SPECIAL GROWTH CHAMBER FOR WHEAT WITH CARBON DIOXIDE RECORDING MECHANISM



2. PLATE CULTURE OF ALGAE EXPOSED TO MERCURY SPECTRUM

EFFECT OF ARTIFICIAL LIGHT AND CONTROLLED HUMIDITY

Greenhouse-grown palm (left) compared with a similar one grown under controlled artificial light and humidity conditions (right). Tremendous growth of roots had burst the pot of the latter and necessitated repotting.

COOPERATIVE WORK WITH THE BUREAU OF PLANT INDUSTRY, DEPARTMENT OF AGRICULTURE

A first experiment has been carried out in the general plan of cooperation between the United States Department of Agriculture and the division, in the crop physiology and breeding investigations of Dr. Walter T. Swingle. In this experiment the effects of controlled radiation, humidity, and temperature on certain tropical and xerophytic plants were investigated in a preliminary way. The results may be summed up as follows:

First, it was found possible to maintain conditions which yielded in the case of date palms, ten times greater growth rate than that exhibited by the control plants in the greenhouse (pl. 2). Second, humidity was shown to be a controlling factor in the growth of date palms. Third, the ephedra under these conditions yielded two crops, both larger than the single crop grown in the greenhouse. Fourth, conditions maintained, perhaps due to the red-rich, blue-poor radiation, yielded exceptional root development in both palms and pandani. Fifth, pandani have shown exceptional offshoot development, a matter of great significance in propagation of identical individuals. If the same proves true of palms, as seems likely, this result is of considerable practical importance.

In this experiment the plant conditions and developments were in the hands of Dr. Florence E. Meier, associate physiologist in the Bureau of Plant Industry. Members of the division assisted during the experiment by the development of control apparatus in connection with a propagating chamber for maintenance of constant humidity and temperature.

In further preparation for the cooperative program the Department of Agriculture has constructed four additional individual growth chambers of a larger and slightly modified design but in general similar to the four already constructed by the division. A humidifier to serve all the individual growth chambers has been constructed by their shops and is in progress of installation. It should be possible to begin experimentation with these individual growth chambers some time during the coming fall.

SPECTROSCOPIC DEVELOPMENTS

INFRA-RED

A large spectrograph, equipped with salt prisms, which will record intensity distribution of radiation from the visible to 15μ in the deep infra-red, is nearly completed. A preliminary grating set-up shows

remarkable possibilities of an old grating ruled for the Smithsonian by Rowland for infra-red work shorter than 6μ. Two echelette gratings have been ruled for the division by the Johns Hopkins University and have been given preliminary tests in the near infra-red. While these tests have so far been discouraging, they may still prove satisfactory in the deeper infra-red beyond 6μ, for which they were more particularly designed.

The near infra-red work has been continued in cooperation with the Fixed Nitrogen Research Laboratory. Investigations of the

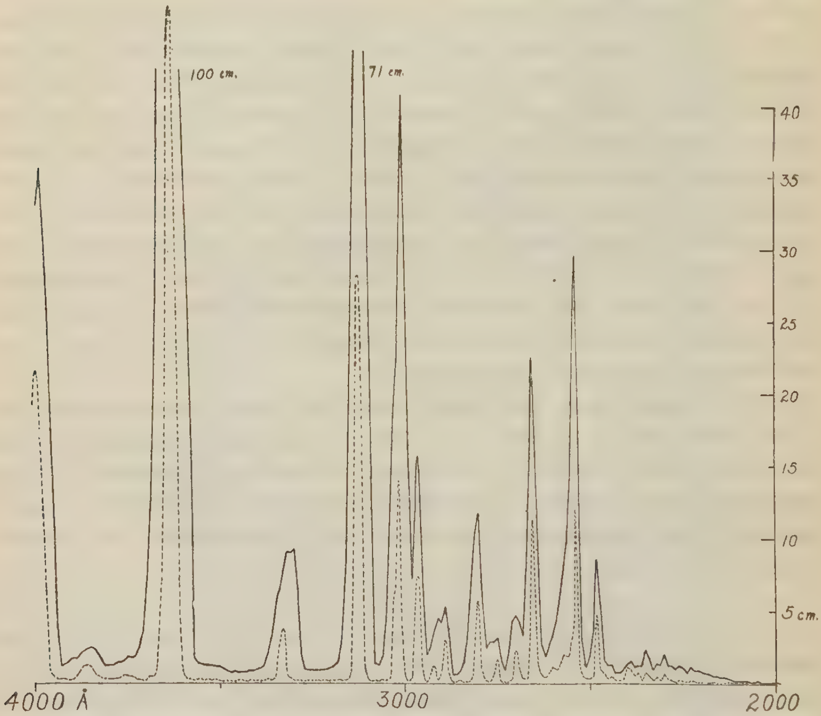


FIGURE 4.—Comparison of spectra using single and double monochromators
——— single monochromator.
-------- double monochromator.

halogen derivatives of benzene have been extended; the near infra-red spectrum of HCN has been investigated in both liquid and vapor, the results being presented at the Pacific coast meetings of the Physical Society during the summer. Investigations of HCl in vapor and dissolved in carbon tetrachloride have been carried out with a view to determining the rotational freedom existing in such solutions. This work has been carried out by Doctor Brackett, in association with Urner Liddel and Dr. Oliver Wulf, of the Fixed Nitrogen Research Laboratory.

ULTRA-VIOLET

The energy distribution in the mercury arc has been measured by Doctor McAlister at a resolution 10 times greater than the previous work. These results were presented at meetings of the Physical Society. This work has been made possible through the loan of two quartz monochromators by the Bausch & Lomb Optical Co. Figure 4 shows by the solid line the spectrum plotted with a single monochromator; it is replotted with dotted lines where two monochromators are used, arranged so that the light passed first through one

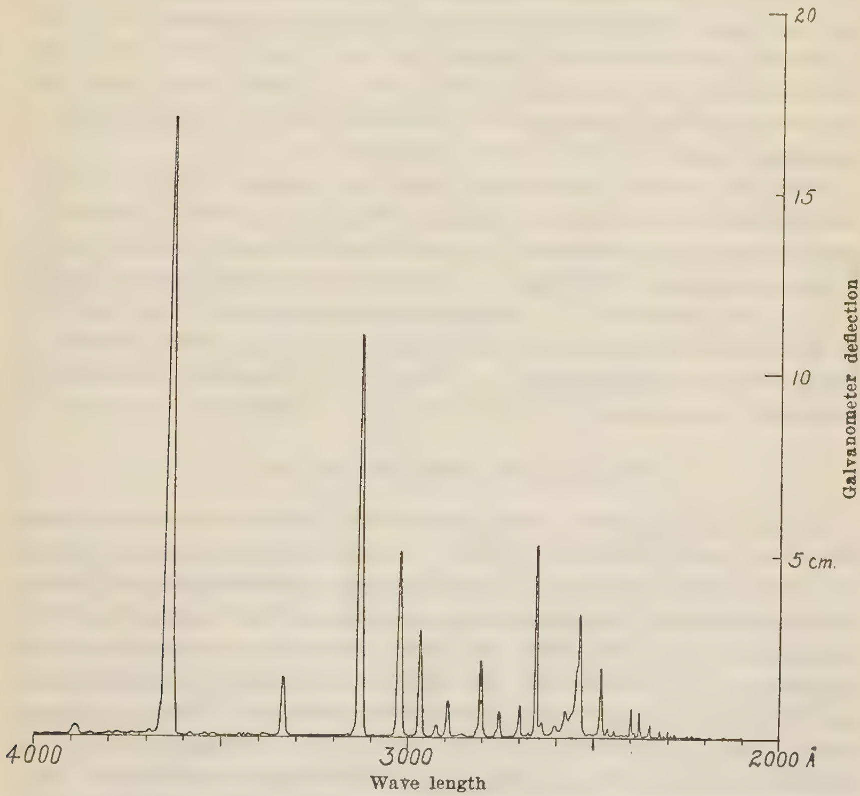


FIGURE 5.—Intensity record of mercury arc spectrum using double monochromator

and then through the other. It will be seen that not only is the background of energy observed between lines greatly reduced, but also the lines are much narrowed, or, in other words, the resolution is greatly increased. The intensities of the lines are only reduced by a factor of two where the resolution and freedom from scattering is increased by a larger factor. Figure 5 shows the spectrum plotted with the double monochromator arrangement but a still narrower slit.

As a result of these measurements of spectral distribution in the visible and ultra-violet, an invitation has been extended to the division to be represented on the committee on ultra-violet measurement standards of the Illuminating Engineers Society. Doctor McAlister represented the division in the first of these meetings during the summer, where plans were made for cooperation in the development of suitable standard sources and technique for intensity measurement.

THERMOCOUPLE TECHNIQUE

As a result of the development of the specially sensitive vacuum thermocouples by members of the division many requests have come in for the construction of couples for other institutions. This has been possible only in exceptional cases. Couples have been constructed for the University of California, for the Department of Agriculture, and for the General Electric Co.

As an adjunct of these highly sensitive couples a special thermocouple multiplier has been developed which is capable of magnifying galvonometer deflections by any desired ratio up to 1,000 times. It has the special advantages of making this magnification linearly for any amplitude and of introducing no appreciable added instability into the measurements. This technique is applicable not only to the infra-red investigations but also to the phototropic experiment where the measurement of extremely small intensities is required.

REPORT ON THE WORK OF INDIVIDUALS

Dr. Earl S. Johnston, plant physiologist, became a full-time member of the staff in February, 1931. Doctor Johnston began his work with the division as a consultant while still a professor at the University of Maryland. He has taken an active part in the plans and developments along the lines of plant physiology almost from the beginning. His addition to the staff has made possible much more rapid progress in the biological phases of the work. He has aggressively pushed the phototropic experiments and the wheat experiment, and has assisted in the preliminary growth chamber experiment. His assistance in matters of publication has been very valuable.

Dr. E. D. McAlister became a member of the staff in September, 1930, devoting half of his time to the work of the division and the other half to the work of the Research Corporation. During the latter part of the year all his time was assigned to the work of the division. Doctor McAlister's long experience in thermocouple technique and infra-red measurements makes him unusually well qualified for the work of the division. He has carried out the most exacting phases of thermocouple observations on intensity and wave-length

distribution in the phototropic experiment. He has materially contributed to the development of the preliminary growth chamber and controls. He has carried out an investigation on the distribution of the mercury arc in the blue and ultra-violet. He has furthermore handled a large part of the technical developments of thermocouples. This is in addition to his work with the Research Corporation, for which he has carried out exhaustive investigations of the possibilities of the thermopile for use as a source of electromotive force in applied fields. He has carried out preliminary developments of the nephylometer for general experimental use.

Leland B. Clark, in addition to carrying on all the regular glassblowing, has handled the vacuum technique development in connection with the thermocouples. He has constructed a practical butylphthalate pump of original design. His assistance in many phases of special laboratory technique is of great value to the division.

William H. Hoover has carried out a large part of the equipment and operation of the preliminary growth chamber; he has adjusted and increased the sensitivity of the carbon dioxide detecting device loaned to the division by the Fixed Nitrogen Research Laboratory and he has installed and put in operation temperature-control equipment for the individual wheat experiment. He has designed and installed a new thermostat which greatly increases the stability of the carbon dioxide recording mechanism. This is in addition to his work with the Astrophysical Observatory, for whom during the year he has spent a month in the development of photometric equipment and two months on a trip to Table Mountain, as well as some computational work on the annual report.

Miss Stanley, in addition to the regular stenographic work, now a considerable load, has ably handled all our bookkeeping in connection with purchases.

L. A. Fillmen, a mechanic of wide experience in apparatus and equipment construction, became a half-time member of the staff in August, 1930. His experience and ability have contributed largely in the development of equipment for the laboratory. Through the courtesy of the Fixed Nitrogen Research Laboratory, Mr. Fillmen worked for several months in their shop while our shop was being equipped.

PERSONNEL

During the fiscal year the personnel was as follows:

Chief.—Dr. Frederick S. Brackett.

Research associate.—Dr. Earl S. Johnston.

Associate research assistant.—Dr. E. D. McAlister.

Research assistant assigned by the Astrophysical Observatory.—W. H. Hoover.

Research assistant.—L. B. Clark.
Stenographer.—Virginia P. Stanley.
Mechanic.—L. A. Fillmen.

EXTENSION OF HOUSING

The large room No. 14 of the basement was added to the laboratory in order to provide for the intensity measurements in the visible and ultra-violet and development of the algae and wheat experiments. Partitions have been built in order to provide sufficient dark-room space. A room has also been constructed in order to make possible the accommodation of a glass-blowing course, which Mr. Clark has undertaken for the Department of Agriculture. Room No. 12 has been equipped as a thoroughly up-to-date machine shop by the Research Corporation, with whom the division shares Mr. Fillmen's time. Room No. 13 has been equipped for the shopwork of the members of the division.

COOPERATION

The division has been especially fortunate in the cordial cooperation of other institutions. This includes near infra-red work with the Fixed Nitrogen Research Laboratory, experiments in higher plants with the Bureau of Plant Industry, sharing of equipment and personnel with the Research Corporation, personal assistance from the Astrophysical Observatory, assistance in the form of apparatus and equipment from the Bausch & Lomb Optical Co. and the General Electric Co.

GENERAL

In undertaking experimental work along those biological lines wherein radiation plays an important part it is inevitable that men are required with special training and experience not only in biology but also in the fields of physics and chemistry. To bring about the cooperation in these border-line problems of men with specialized training in each of these fields has been the essential dominating idea in the development of the division. The lack of men with specialized chemical training in the organic and photochemical fields is more and more keenly felt. Furthermore although the division is well provided with people of highly specialized training in the field of plant physiology and physics it is handicapped by the lack of sufficient laboratory assistance in order to carry out their ideas and make their time effective. Without increasing its program or widening the scope of its activities the division urgently needs sufficient funds to round out its personnel in this way.

SUMMARY

The end of the second year finds the research work of the division well under way with preliminary results on phototropism, and on carbon dioxide assimilation of wheat; algae experiments on light adaptation have been initiated; promising experimental work has been begun in cooperation with the Department of Agriculture; and spectroscopic measurements have been completed in both the ultra-violet and infra-red. The laboratory space has been extended and equipped for the expansion of the work. Shop facilities have been added to care for the apparatus development. Essential additions have been made to the division personnel in both the physiological and physical sides of the project.

Respectfully submitted.

F. S. Brackett, *Chief.*

Dr. C. G. Abbot,

Secretary, Smithsonian Institution.

APPENDIX 9

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

Sir: I have the honor to submit the following report on the operations of the United States Regional Bureau of the International Catalogue of Scientific Literature for the fiscal year ending June 30, 1931.

The routine work of the bureau, consisting mainly of compiling necessary records of current American scientific publications to be indexed for the catalogue when publication is resumed, has been continued.

In compliance with the resolution passed at the last international convention held in Brussels in July, 1922, this bureau has been kept in existence. This resolution, unanimously adopted, was " That the convention is of opinion that the international organization should be kept in being through mutual agreement to continue as far as possible the work of the regional bureaus until such time as it may be economically possible to resume publication." Complying with the intent of the resolution, this bureau has been continued, though with a force of only two employees, in order to keep the enterprise alive with the lowest possible expenditure of money. Each year part of the regular annual congressional appropriation has reverted to the Treasury; this year, out of the appropriation of $8,145, only $5,624 was spent, and thus $2,521 will revert.

This bureau is making every effort through the chairman of the executive committee, in whom authority to reorganize is vested, to influence the other bureaus to take the steps necessary to resume publication, but on account of depressed financial conditions still existing and the disorganized political situation in some countries no definite plan has yet been advanced. This is a situation to be deplored, for nothing has ever taken the place of the catalogue, and its need in the world of science becomes ever more obvious. Aside from the necessary cooperation by the regional bureaus in furnishing classified references for the Catalogue, a capital fund estimated at $75,000 is needed to refinance the central bureau, the editing and publishing center of the enterprise, and it seems probable that when a definite plan is presented some of the great endowed foundations interested in this and similar fields will provide this comparatively small sum.

Dr. Ernest Cushing Richardson, one of the great international authorities on bibliography, stated in a paper on the International Catalogue published in Science, June 20, 1930:

> * * * The research endowments are bombarded with bibliographical projects of varying method and degrees of merit. They aid or support a good many projects. They are deeply concerned as trust organizations to put their money where it will do the most good. Other things being equal, they prefer to put it where one dollar will do the work of four. * * * It is here they can give the most bibliographical service with the least money. The proposition touches the libraries in a very similar way. If and when the matter is revived it will depend for financing, if not on the endowments, than on library subscriptions. If this machine is scrapped, when a new one is started either a $3,000,000 endowment must be had from promoters of research or a quadruple price charged to libraries.

Respectfully submitted.

Leonard C. Gunnell,
Assistant in Charge.

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON THE LIBRARY

Sir: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1931:

THE LIBRARY

The library, or library system, of the Smithsonian Institution is made up of 46 separate libraries, each related in some special way to the work of the Institution and of the seven Government bureaus under its administrative charge. The chief of these is the Smithsonian deposit in the Library of Congress. The others are the library of the United States National Museum, the Smithsonian office library, the Langley aeronautical library, and the libraries of the Astrophysical Observatory, the Bureau of American Ethnology, the Division of Radiation and Organisms, the Freer Gallery of Art, the National Gallery of Art, and the National Zoological Park, together with the 36 sectional libraries in the National Museum. These collections, which number in all about 800,000 volumes, pamphlets, and charts, not to mention the thousands still uncatalogued, while they contain many publications on art, history, literature, philosophy, music, and education, pertain largely to science and technology. This important group of libraries has made available to Smithsonian employees and to American research workers in general, especially those connected with the various departments of the Government, most of the leading scientific publications of the world during one of its outstanding eras. Thus it has had a noteworthy part in carrying out since 1846—the year in which the Smithsonian began its activities—the will of James Smithson, the founder of the Institution.

CHANGES IN STAFF

During the last year there were several changes in the library staff. Miss Marian W. Seville was made head of the order department and promoted from the rank of library assistant to that of senior library assistant. Mrs. M. Landon Reed, who had served in the exchange department for some time on temporary appointment, was given a permanent position as clerk. Miss Margaret Moreland

was advanced from the grade of under library assistant to that of senior stenographer, to fill a new position established in the librarian's office at the beginning of the year. Miss Anna M. Link was promoted from the rank of minor library assistant to the place formerly occupied by Miss Moreland. Miss Virginia C. Whitney, a graduate in library science of George Washington University, was appointed minor library assistant to succeed Miss Link. The temporary employees were Mr. Alan Blanchard, Mrs. Daisy Cadle, Mrs. Lewis Deschler, Miss Katherine Everhart, Mrs. Grace A. Parler, Miss Jennette Seiler, Miss Eleanor Spielman, and Mr. Clyde Williams.

EXCHANGE OF PUBLICATIONS

The collections in the library system have been built up partly by the early provisions of the copyright law, partly by purchase and gift, but to a very large extent by exchange, for from the first the Institution and its branches have exchanged their publications for those of other learned institutions and societies and for scientific and technical journals and monographs. These have come to the Smithsonian library by mail or through the International Exchange Service, which is administered by the Institution.

In the course of the fiscal year just closed there came to the library by mail 24,594 packages and by the Exchange 1,688, each containing one or more publications. These were stamped, entered, and forwarded to the appropriate libraries of the system. Among the notable sendings, of which there were many, was one of 331 volumes and parts of Neerlandia from the Allgemeen Nederlandsch Verbond, at The Hague. This was assigned to the Smithsonian deposit.

The publications received included 4,565 dissertations from the universities of Basel, Berlin, Bern, Bonn, Breslau, Cornell, Erlangen, Gand, Giessen, Greifswald, Halle, Heidelberg, Helsingfors, Jena, Johns Hopkins, Kiel, Königsberg, Leiden, Leipzig, Lund, Marburg, Neuchâtel, Pennsylvania, Rostock, Strasbourg, Tübingen, Utrecht, Warsaw, and Zürich, the Academy of Freiberg, and technical schools at Aachen, Berlin, Braunschweig, Dresden, Karlsruhe, and Zürich.

Of the 1,808 letters written by the library staff during the year—an increase of 97 over 1930—nearly all had to do with the exchange of publications. At the close of the year this correspondence was up to date. The number of publications obtained in exchange in response to special requests from the various libraries of the Institution was much larger than usual, or 3,590. Exchange relations for several hundred new publications were entered into, particularly on behalf of the Smithsonian deposit, the Langley aeronautical library, and the libraries of the National Museum and Astrophysical Observatory.

GIFTS

During the year the library received many gifts. Chief among these was one of several thousand volumes and pamphlets, together with a collection of important letters and photographs, from the library of the late Dr. George P. Merrill, head curator of geology. These were presented by Mrs. Merrill and the other heirs of the estate and are to be kept in the office formerly occupied by Doctor Merrill, both as a permanent memorial to him and as an outstanding addition to the library in the division of geology. Other valuable collections received were as follows: 600 publications of a general scientific nature from Mrs. Dora W. Boettcher, given in memory of her husband, F. L. J. Boettcher, who was once connected with the Smithsonian Institution; 386 volumes and pamphlets from the heirs of the estate of the late Dr. O. P. Hay, of the Carnegie Institution, who for some years before his death used the library in the National Museum almost daily and gave it many valuable publications; 34 volumes, especially on atomic weights, together with a package of letters from the first four Secretaries of the Smithsonian, from the late Dr. Frank Wigglesworth Clarke; 30 publications by or about Prof. Henry Carvill Lewis, from his sister, Mrs. Edward S. Sayres; and 50 or more early numbers of periodicals on art, from Mrs. Marietta Comly. Among other gifts were 8 volumes on the history of Japan, from the Historiographical Institute, Tokyo; 4 volumes, namely, A Handbook of Mohammedan Decorative Arts, by M. S. Dimand, and Catalogue of European Daggers, Catalogue of European Court Swords and Hunting Swords, and Handbook of Arms and Armor, European and Oriental, by Bashford Dean, from the Metropolitan Museum of Art; and The Permian of Mongolia, by Amadeus W. Grabau, from the American Museum of Natural History. About 600 publications came from the American Association for the Advancement of Science, 267 from the International Catalogue of Scientific Literature, 255 from the Geophysical Laboratory, 55 from the American Association of Museums, and many from the Library of Congress.

Preeminent among the books presented to the library was a copy of Nippon, by Phillip Franz von Siebold, as reissued recently in five volumes by the Japaninstitut of Berlin. The narrative of the author's experiences in Japan during the years 1823 to 1830 is illustrated with pictures of the Japanese people and life during that period. This handsome and costly work, highly significant for its worth both as art and as history, was given to the Smithsonian by G. A. Pfeiffer, of New York, and was deposited in the library of the Freer Gallery of Art. Other unusual gifts included Machu Picchu, a Citadel of the Incas, by Senator Hiram Bingham, from

the National Geographic Society; Lo-Lang, a Report on the Excavation of Wang-Hsü's Tomb in the Lo-Lang Province, an Ancient Chinese Colony in Korea, by Yoshito Harada, with the Collaboration of Kingo Tazawa, from the Tokyo Imperial University; The Ellsworth Family, Volume II—Lincoln Elsworth, by Howard Eldred Kershner, from the National Americana Society; Impressions of Japanese Architecture, by Ralph Adams Cram, from the Japan Society of New York; Volumes IV and V of her well-known work, North American Wild Flowers, from Mrs. Charles D. Walcott; Volumes VII and VIII of the Smithsonian Scientific Series—Man from the Farthest Past, by Carl Whiting Bishop, and Cold-Blooded Vertebrates (Pt. I, Fishes; Pts. II and III, Amphibians and Reptiles), by Samuel F. Hildebrand, Dr. Charles W. Gilmore, and Doris M. Cochran—from the Smithsonian Institution; Clouds, by Alexander McAdie, from the Blue Hill Observatory; The Travels of Captain Robert Coverte, edited and presented by Boies Penrose; Wild Flowers of the Alleghanies, by Joseph E. Harned, from the author; William Henry Welch at Eighty, edited by Victor O. Freeburg, from the Milbank Memorial Fund; The Indians of Pecos Pueblo, by Earnest A. Hooton, from Phillips Academy; Handbook of Aeronautics, by the Royal Aeronautical Society of London, from the publishers, Gale & Polden (Ltd.); African Republic of Liberia and the Belgian Congo (Harvard African Expedition, 1926–27), in two volumes, edited by Richard P. Strong, from Harvey W. Firestone; Natural History of Birds, in two volumes, by George Edwards, from James Norris Woodward; and Tratado Elemental de Botánica, with typed index, by Carlos Cuervo Márgues, from W. A. Archer.

Gifts were also received from many members and associates of the Smithsonian staff, including Secretary Abbot, Assistant Secretary Wetmore, Dr. William H. Holmes, director of the National Gallery of Art, Dr. J. M. Aldrich, H. G. Barber, Dr. Marcus Benjamin, E. J. Brown, Dr. E. A. Chapin, A. H. Clark, Dr. Herbert Friedmann, Dr. O. P. Hay, Dr. Walter Hough, A. B. Howell, Dr. Aleš Hrdlička, Neil M. Judd, Dr. Remington Kellogg, Dr. W. R. Maxon, G. S. Miller, jr., A. J. Olmsted, J. C. Proctor, Miss Mary J. Rathbun, W. deC. Ravenel, Dr. C. W. Richmond, J. H. Riley, J. Townsend Russell, jr., Dr. Waldo Schmitt, Miss Marian Seville, and E. H. Walker.

SMITHSONIAN DEPOSIT

The Smithsonian deposit in the Library of Congress is, as has been said, the chief unit in the library system, numbering at present more than 500,000 volumes, pamphlets, and charts. It is peculiarly rich in scientific monographs, the reports, proceedings, and trans-

actions of learned institutions and societies, and scientific and technical journals. To the scholar, therefore, particularly in the fields of natural history, physical science, and technology, the deposit offers a wealth of material.

During the last fiscal year the Institution sent to the deposit 20,879 publications—an increase of 1,735 over the year before—or 2,626 volumes, 12,775 parts of volumes, 4,393 pamphlets, and 1,085 charts. Of these, 4,565 were dissertations. Of the charts, 883 were maps and atlases which the Smithsonian, in the course of the reorganization of its library system, had selected as worthy of preservation in its main library. Some of these were important manuscript maps; many of the others were also new to the division of maps in the Library of Congress.

The number of publications obtained by the Smithsonian library in exchange to meet special needs in the deposit was 2,364, or 159 more even than in 1930, when the records showed more than a two and a half fold increase over 1929 and almost a fivefold increase over 1928. This steady growth in the exchange service of the library on behalf of the deposit is worthy of note.

In addition to the publications sent to the deposit, several thousand documents of foreign governments, which were received by the Smithsonian library, were forwarded, without being stamped and entered, to the division of documents in the Library of Congress.

It might be added that toward the close of the year the Smithsonian library, with the aid of the National Museum, especially the section of photography, took steps, at the happy suggestion of the chief of the Smithsonian division in the Library of Congress, to have portraits made of the founder and five Secretaries of the Smithsonian Institution to be hung in that division with those of other prominent scientists already there. When they are finished, they will be presented for this purpose.

NATIONAL MUSEUM LIBRARY

In the library system of the Smithsonian Institution the library of the United States National Museum ranks next in size and influence to the Smithsonian deposit. Its 2 major and 36 minor collections are largely on natural history and technology. The catalogued items of the library total 79,407 volumes and 109,129 pamphlets. During the fiscal year 1931 the accessions to it were 2,528 volumes and 832 pamphlets, an increase of 375 over 1930. Many of these came by gift, more by purchase, but most by exchange.

The year was one of much progress, in which the staff went far toward making the library a more complete and available instrument in the research work of the museum. This was the result partly of the appointment to the Museum and other permanent library rolls

of the Smithsonian of several new trained assistants and partly of the increase in funds for the acquisition of material needed by the scientists which could not be obtained by exchange. The staff entered 8,799 periodicals, substituting for the old system of entry a new system that is being employed extensively by libraries using Library of Congress cards. They catalogued 1,639 volumes, 785 pamphlets, and 17 charts, or 427 more than the previous year. They also, as in former years, did the cataloguing and entering for the library of the National Gallery of Art, the total number of publications thus treated being 311 and 533 respectively—twice the number of 1930. They contributed 11,193 cards to the Museum catalogue and revised 672 catalogue headings. They also added 8,036 cards to the shelf lists, and prepared almost as many duplicate cards for the union shelf list in the Smithsonian Building. They sent to the sectional libraries 6,522 volumes and parts and to the members of the scientific staff for their personal use 1,419 reprints, many of which had come to light in the process of sorting the few remaining collections of miscellaneous material in the library. They filed the Wistar Institute cards as they came in, and brought up to date the filing of the large accumulation of Concilium Bibliographicum cards of the author set, 17,000 cards being added to this file. The current cards of the systematic set were forwarded to the sections that have files on their special subjects. The number of volumes bound was 1,402, or 131 more than in 1930. In this connection it may be added that more volumes than usual were completed by special exchange letters, the number of publications received in response to them being 1,090, an increase of 402 over the year before.

The number of publications loaned to the staff of the Smithsonian and its branches totaled 7,221, more than one-third of which were charged in the reading room of the Arts and Industries Building. Of these the library borrowed 2,049 from the Library of Congress and 271 elsewhere. Loans of 142 publications were made to libraries not in the Smithsonian system. The number of volumes returned to the Library of Congress was 2,519 and to other libraries 407—in each instance many more than usual.

The main shelf list—that of the collection in the Natural History Building—was completed early in the year, and the work of taking an inventory was begun. This had to be discontinued, however, in the fall, owing to lack of help.

Finally, attention should be called to the fact that even with the 400 feet of new shelving that the Museum installed for the collection in 1930 the natural history library is still in a very crowded condition. Sufficient space and equipment both to relieve its present congestion and to permit of growth for a period of years should be provided as soon as possible.

During the year the Museum library staff was able to assist only a few of the sectional libraries with their special problems, including those in the divisions of plants, mammals, and geology.

These libraries number 36, and are as follows:

Administration.
Administrative assistant's office.
American archeology.
Anthropology.
Biology.
Birds.
Botany.
Echinoderms.
Editor's office.
Ethnology.
Fishes.
Foods.
Geology.
Graphic arts.
History.
Insects.
Invertebrate paleontology.
Mammals.
Marine invertebrates.
Mechanical technology.
Medicine.
Minerals.
Mineral technology.
Mollusks.
Old World archeology.
Organic chemistry.
Paleobotany.
Photography.
Physical anthropology.
Property clerk's office.
Reptiles and batrachians.
Superintendent's office.
Taxidermy.
Textiles.
Vertebrate paleontology.
Wood technology.

OFFICE LIBRARY

The office library consists of works of general reference, sets of the publications of the Smithsonian and its branches, and of various foreign societies and institutions, as well as numerous publications of a less learned and more cultural and even recreational character for use during the leisure hours of the Smithsonian employees. The additions to the library in the course of the last 12 months were 686 volumes and 32 pamphlets. The number of periodicals entered was 229.

BUREAU OF AMERICAN ETHNOLOGY LIBRARY

The library of the Bureau of American Ethnology contains 26,671 volumes and 16,717 pamphlets, chiefly on the archeology, history, myths, religion, arts, sociology, language, and general culture of the early peoples of the Western Hemisphere, especially of the North American Indian. The collection was increased during the past year by 600 volumes and 190 pamphlets. The number of periodicals entered was 3,500, and of cards added to the catalogue 3,500. The number of volumes bound was 473. The loans were 875.

ASTROPHYSICAL OBSERVATORY LIBRARY

The library of the Astrophysical Observatory is closely related in content to the researches in astrophysics and meteorology that are

being conducted by the Institution. It has 4,188 volumes and 3,192 pamphlets. The additions during the year were 180 volumes and 92 pamphlets. The number of volumes bound was 127.

RADIATION AND ORGANISMS LIBRARY

The library of radiation and organisms is a small, highly specialized collection pertaining to one of the newer interests of the Institution, for the furthering of which it recently organized a division. During 1930 publications bearing mainly on this interest to the number of 20 volumes, 1 pamphlet, and several periodicals were added, bringing the collection to 94 volumes, 9 pamphlets, and 6 charts. Space and equipment, adequate for some years to come, were provided for the library in the north tower of the Smithsonian Building.

LANGLEY AERONAUTICAL LIBRARY

The Smithsonian's well-known collection of aeronautical publications is now deposited in the Library of Congress, where, under its own stamp and bookplate, it occupies a unique place in the division of aeronautics and is even more available as an aid in research than it was before 1930, when it was transferred from the Institution. It will continue to bear the name of the Langley Aeronautical Library, in memory of Samuel Pierpont Langley, who while Secretary of the Smithsonian made a notable contribution to the science of aeronautics. Most of the collection once belonged to Doctor Langley, and to other experimenters associated with him, including Alexander Graham Bell, Octave Chanute, and James Means. The rest of it has been received from time to time by the Institution chiefly in exchange for its publications. The library contains 1,856 volumes and 1,056 pamphlets. Among its items are sets, including most of the early numbers, of the aeronautical magazines, both American and foreign, and many other important publications, some of which are very rare, together with files of photographs, letters, and newspaper clippings.

During the fiscal year just closed the Smithsonian library was instrumental in increasing the Langley collection by 45 per cent more than in 1930, or by 122 volumes, 445 parts of volumes, and 133 pamphlets. Most of these were obtained by exchange. In this connection it may be added that the library, cooperating with the division of aeronautics in the Library of Congress, entered into exchange relations, on behalf of the Langley collection, with 50 or more new aeronautical societies and institutions, and received in response to its special requests many publications. It is hoped that this service on the part of the Smithsonian library can be considerably enlarged in the near future.

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NATIONAL GALLERY OF ART LIBRARY

The library of the National Gallery of Art contains many valuable works on art, both American and foreign, including sets of the leading magazines. The collection numbers 1,243 volumes and 1,332 pamphlets. During the last year its accessions were 145 volumes, 166 pamphlets, and 533 periodicals. Most of these came by purchase and exchange. Numerous gifts were received, however, especially from Dr. William H. Holmes, director of the gallery, and James Townsend Russell, jr., honorary collaborator in Old World archeology in the National Museum. The number of volumes bound was 51.

FREER GALLERY OF ART LIBRARY

The library of the Freer Gallery of Art is a prominent member of the Smithsonian library system. As the collection has to do largely with the arts and cultures of the Far East, India, Persia, and the nearer east, it is not only a unique and valuable aid to those immediately connected with the gallery, as well as to visitors who come there for research, but in many of its items—notably those in Chinese and Japanese, not a few of which are extremely rare—it supplements to an unusual degree the collection in the oriental division of the Library of Congress. In the library, too, are works on the lives and art of various American painters, especially James McNeill Whistler, a large number of whose pictures are owned by the gallery. It also has numerous publications on the Washington manuscripts, the well-known fourth and fifth century manuscripts of the Bible, which are among the treasures of the gallery.

The main library, which is kept permanently in the gallery, consists of 4,423 volumes and 3,148 pamphlets. Its accessions during the year just closed were 61 volumes and 150 pamphlets. The number of volumes bound was 20. In addition to its main library, the gallery has a special collection, numbering 814 volumes and 500 pamphlets, chiefly of archeological interest, which is for the use of its staff in the field. Among the significant publications deposited in the library during the year by the Smithsonian Institution were a copy of Nippon, by Phillip Franz von Siebold, and of Lo-Lang, by Yoshito Harada and Kingo Tazawa—two of the gifts described in more detail earlier in this report. The work of reclassifying and recataloguing the collections, which was begun the year before, was carried almost to completion, 6,083 cards being added to the dictionary catalogue of the library and a like number being prepared for filing in the union catalogue in the Smithsonian Building. This notable progress was made possible by the further generous cooperation of the gallery with the Smithsonian library. Of the 435 visitors, 216 came

to study, 16 to make sketches from plates, and 203 to see the reproductions of the Washington manuscripts.

NATIONAL ZOOLOGICAL PARK LIBRARY

Among the 1,217 volumes and 407 pamphlets in the library of the National Zoological Park are many of great value to those interested in the care and habits of animals. Its additions for the year were four volumes and four pamphlets.

SUMMARY OF ACCESSIONS

The accessions for the year may be summarized as follows:

Library	Volumes	Pamphlets and charts	Total
Astrophysical Observatory	180	92	272
Bureau of American Ethnology	600	190	790
Freer Gallery of Art	61	150	211
Langley Aeronautical	122	133	255
National Gallery of Art	145	166	311
National Zoological Park	4	4	8
Radiation and Organisms	20	1	21
Smithsonian deposit, Library of Congress	2, 626	5, 478	8, 104
Smithsonian office	686	32	718
United States National Museum	2, 528	832	3, 360
Total	6, 972	7, 078	14, 050

It is estimated that on June 30, 1931, the number of volumes, pamphlets, and charts in the Smithsonian library system was as follows:

Volumes	578, 057
Pamphlets	192, 477
Charts	26, 346
Total	796, 880

In addition to this total, there were, of course, many thousands of volumes still uncatalogued or awaiting completion.

UNION CATALOGUE

Besides keeping up the current cataloguing work, the staff completed the shelf list of the National Museum library and prepared a copy of part of it for filing with the union shelf list in the Smithsonian Building; catalogued and arranged the publications of the Carnegie Institution of Washington; finished cataloguing the John Donnell Smith collection, including a large set of miscellaneous publications, for which they prepared about 1,100 analytical and subject entries; began the recataloguing of the general botanical collection in the National Museum; and, finally, made notable prog-

ress in the work, begun the year before, of reclassifying and recataloguing the library of the Freer Gallery of Art.

The work on the union catalogue and shelf list may be summed up by the following statistics:

Volumes catalogued	5,127
Volumes recatalogued	37
Pamphlets catalogued	2,754
Pamphlets recatalogued	3
Charts catalogued	219
Typed cards added to catalogue	7,896
Library of Congress cards added to catalogue	14,949
Museum cards copied for union shelf list	13,219
Freer cards prepared for union catalogue and shelf list, to be added later	7,551

SPECIAL ACTIVITIES

A number of special tasks were undertaken by the staff during the year. These were chiefly connected with the reorganization of the library system that has been going on for some time.

Further progress was made in sorting the miscellaneous material in the west stacks of the Smithsonian Building, and hundreds of publications were found that were lacking in the libraries of the Institution. The art-room collection was checked and a list prepared for the National Gallery of Art. The regents' and archives' sets of Smithsonian publications were also checked and, so far as possible, the missing numbers supplied. The natural history collection in the National Museum was shifted and rearranged, to make it less crowded and more accessible, and a similar treatment of the technology collection was begun.

Many publications—in some cases, whole files—not needed by the Institution or its branches, were transferred to other Government libraries. These included 1,935 publications of the United States Geological Survey, 904 of the Canadian Geological Survey, and 100 of a miscellaneous character. They likewise included the rolls of 883 maps and atlases that had been stored for many years in the old Museum.

Four hundred and fifty of the duplicates among the publications of the Carnegie Institution of Washington were sent back to that institution. In return the Carnegie give the Smithsonian many of the volumes that were lacking in its sets. The duplicate publications of the University of California received similar treatment, 476 items being returned to the university and a large number sent to the Institution toward completing its files.

The librarian gave several lectures, on Shakespeare, Virgil, the Nature of Poetry, and the Smithsonian Institution, before various

groups in Washington, including the Cosmos Club, the Shakespeare Society, the Classical Club, and American University.

CONCLUSION

Despite the fact that the year was one of the most successful since the beginning of the reorganization of the library system in 1924, much more could have been accomplished both for the libraries in the system and for the scientists and other employees of the Smithsonian if sufficient funds had been at hand for the purchase of all the books and periodicals not obtainable by exchange that were needed in the current work of the Institution; if the binding allotment had been large enough to permit the binding of all the volumes prepared during the year—as it was, 600 had to be held for months as they could not be sent to the bindery until after June 30; and, most of all, if it had been possible to employ more permanent trained assistants. Among the additional personnel needed on the library staff are several cataloguers and general library assistants, a typist, and a messenger.

Respectfully submitted.

William L. Corbin, *Librarian.*

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 11

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government bureaus under its administrative charge during the year ending June 30, 1931:

A consolidation of all the editorial work of the Institution and its branches, put in effect by the secretary on March 1, 1931, brought all of the 13 series of publications issued by the Smithsonian under the general direction of the editor. This step was taken in the interests of greater unity of editorial policy, more efficiency, and less duplication in the keeping of the many records, financial and otherwise, necessary in an editorial office, and, most important of all, greater accuracy and more prompt appearance of Smithsonian publications.

On January 31, 1931, Dr. Marcus Benjamin, editor of the National Museum, retired after a service of 35 years. He was succeeded by Paul H. Oehser, formerly on the editorial staff of the Bureau of Biological Survey. Mr. Oehser and Mr. Stanley Searles, editor of the Bureau of American Ethnology, will continue in charge of the editorial work of their respective bureaus, but by centralizing the general direction of the work in the office of the editor of the Smithsonian Institution, the advantage is gained of establishing a definite point of contact between heads of bureaus, authors, and the Government Printing Office. Furthermore, the same general style can now be adopted for all the series published under the Institution, so that authors, many of whom publish in several of the series, will know beforehand what style is expected. To aid toward this end, it is proposed to issue a condensed style sheet based on the Style Manual of the Government Printing Office, covering those matters that occur constantly in every manuscript and concerning which authors and typists are often in doubt.

PUBLICATIONS ISSUED DURING THE YEAR

The Institution proper published during the year 16 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report and pamphlet copies of the 24 articles contained in the report appendix, and 3 special publications. The United States National Museum

issued 1 annual report, 1 volume of proceedings, 3 complete bulletins, 1 part of a bulletin, 1 complete volume, 1 part and 1 index in the series Contributions from the National Herbarium, and 40 separates from the proceedings. The Bureau of American Ethnology published two annual reports and three bulletins.

Of these publications there were distributed 205,711 copies, which included 29 volumes and separates of the Smithsonian Contributions to Knowledge, 27,425 volumes and separates of the Smithsonian Miscellaneous Collections, 25,984 volumes and separates of the Smithsonian annual reports, 4,627 Smithsonian special publications, 37,967 copies of the Brief Guide to the Smithsonian Institution, 86,680 volumes and separates of the various series of the National Museum publications, 29,475 publications of the Bureau of American Ethnology, 118 publications of the National Gallery of Art, 1,355 publications of the Freer Gallery of Art, 10 volumes of the Annals of the Astrophysical Observatory, 65 reports of the Harriman Alaska Expedition, and 1,036 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 73, 1 paper was issued; volume 82, 10 papers; volume 83, 1 paper and index and table of contents, comprising the whole volume; volume 84, 1 paper and index and table of contents, comprising the whole volume; and volume 85, 3 papers; making 16 papers in all, as follows:

VOLUME 73

No. 7. Opinions Rendered by the International Commission on Zoological Nomenclature: Opinions 115 to 123. 36 pp. (Publ. 3072.)

VOLUME 82

No. 8. Four New Raccoons from the Keys of Southern Florida. By E. W. Nelson. July 10, 1930. 12 pp., 5 pls. (Publ. 3066.)

No. 9. The Further and Final Researches of Joseph Jackson Lister upon the Reproductive Processes of Polystomella Crispa (Linné). By Edward Heron-Allen, F. R. S. November 26, 1930. 11 pp., 7 pls. (Publ. 3067.)

No. 10. Morphology of the Bark Beetles of the Genus Gnathotrichus Eichh. By Karl E. Schedl. January 24, 1931. 88 pp., 40 text figs. (Publ. 3068.)

No. 12. The Five Monacan Towns in Virginia, 1607. By David I. Bushnell, jr. November 18, 1930. 38 pp., 14 pls. (Publ. 3070.)

No. 13. A Note on the Skeletons of Two Alaskan Porpoises. By Gerrit S. Miller, jr. December 23, 1930. 2 pp., 1 pl. (Publ. 3107.)

No. 14. The Supposed Occurrence of an Asiatic Goat-Antelope in the Pleistocene of Colorado. By Gerrit S. Miller, jr. December 22, 1930. 2 pp., 2 pls. (Publ. 3108.)

No. 15. Three Small Collections of Mammals from Hispaniola. By Gerrit S. Miller, jr. December 24, 1930. 10 pp., 2 pls. (Publ. 3109.)

No. 16. The Ductless Glands of Alligator mississippiensis. By A. M. Reese. March 9, 1931. 14 pp., 3 pls. (Publ. 3110.)

No. 17. The Types of Lamarck's Genera of Shells as Selected by J. G. Children in 1823. By A. S. Kennard, A. L. S., A. E. Salisbury, and B. B. Woodward, F. L. S. July 11, 1931. 40 pp. (Publ. 3112.)

No. 18. Tropisms and Sense Organs of Coleoptera. By N. E. McIndoo. April 18, 1931. 70 pp., 2 pls., 19 text figs. (Publ. 3113.)

VOLUME 83

(Whole volume.) The Skeletal Remains of Early Man. By Aleš Hrdlička. July 24, 1930. 379 pp., 93 pls., 39 text figs. (Publ. 3033.)

Title-page and table of contents. 8 pp. (Publ. 3075.)

VOLUME 84

(Whole volume.) A History of Applied Entomology (Somewhat Anecdotal). By L. O. Howard. November 29, 1930. 564 pp., 51 pls. (Publ. 3065.)

Title-page and table of contents. 8 pp. (Publ. 3118.)

VOLUME 85

No. 1. Weather Dominated by Solar Changes. By C. G. Abbot. February 5, 1931. 18 pp., 4 text figs. (Publ. 3114.)

No. 2. The Avifauna of the Pleistocene in Florida. By Alexander Wetmore. April 13, 1931. 41 pp., 16 figs., 6 pls. (Publ. 3115.)

No. 3. Addenda to Descriptions of Burgess Shale Fossils. By Charles D. Walcott. 46 pp., 23 pls., 11 text figs. (Publ. 3117.)

SMITHSONIAN ANNUAL REPORTS

Report for 1929.—The complete volume of the Annual Report of the Board of Regents for 1929 was received from the Public Printer in November, 1930.

Annual Report of the Board of Regents of the Smithsonian Institution showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1929. xiii+622 pp., 91 pls., 56 text figs. (Publ. 3034.)

The appendix contained the following papers:

The Physics of the Universe, by Sir James Jeans.

Counting the Stars and Some Conclusions, by Frederick H. Seares.

The Lingering Dryad, by Paul R. Heyl.

What is Light? by Arthur H. Compton.

Artificial Cold, by Gordon B. Wilkes.

Photosynthesis, by E. C. C. Baly.

Newly Discovered Chemical Elements, by N. M. Bligh.

Synthetic Perfumes, by H. Stanley Redgrove.

X-Raying the Earth, by Reginald A. Daly.

Extinction and Extermination, by I. P. Tolmachoff.

The Gulf Stream and its Problems, by H. A. Marmer.

The Mystery of Life, by F. G. Donnan.

The Transition from Live to Dead; the Nature of Filtrable Viruses, by A. E. Boycott.

Heritable Variations, their Production by X rays, and their Relation to Evolution, by H. J. Muller.

Social Parasitism in Birds, by Herbert Friedmann.

How Insects Fly, by R. E. Snodgrass.

Climate and Migrations, by J. C. Curry.

Ur of the Chaldees: More Royal Tombs, by C. Leonard Woolley.

The Population of Ancient America, by H. J. Spinden.

The Aborigines of the Ancient Island of Hispaniola, by Herbert W. Krieger.

The Beginning of the Mechanical Transport Age in America, by Carl W. Mitman.

The Servant in the House; a Brief History of the Sewing Machine, by Frederick L. Lewton.

Thomas Chrowder Chamberlin (1843–1928), by Bailey Willis.

Hideyo Noguchi, by Simon Flexner.

Report for 1930.—The report of the executive committee and proceedings of the Board of Regents of the Institution and the report of the secretary, both forming parts of the annual report of the Board of Regents to Congress, were issued in December, 1930.

Report of the executive committee and proceedings of the Board of Regents of the Smithsonian Institution for the year ending June 30, 1930. 14 pp. (Publ. 3074.)

Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1930. 140 pp., 5 text figs. (Publ. 3073.)

The general appendix to this report, which was in press at the close of the year, contains the following papers:

Beyond the Red in the Spectrum, by H. D. Babcock.

Growth in our Knowledge of the Sun, by Charles E. St. John.

The Modern Sun Cult, by J. W. Sturmer.

The Moon and Radioactivity, by V. S. Forbes.

Modern Concepts in Physics and their Relation to Chemistry, by Irving Langmuir.

Waves and Corpuscles in Modern Physics, by Louis de Broglie.

New Researches on the Effect of Light Waves on the Growth of Plants, by F. S. Brackett and Earl S. Johnston.

The Autogiro: Its Characteristics and Accomplishments, by Harold F. Pitcairn.

Ten Years' Gliding and Soaring in Germany, by Prof. Dr. Walter Georgii.

The First Rains and their Geological Significance, by Asaar Hadding.

Weather and Glaciation, by Chester A. Reeds.

Wild Life Protection: An Urgent Problem, by Ernest P. Walker.

The Nesting Habits of Wagler's Oropendola on Barro Colorado Island, by Frank M. Chapman.

The Rise of Applied Entomology in the United States, by L. O. Howard.

Man and Insects, by L. O. Howard.

The Use of Fish Poisons in South America, by Ellsworth P. Killip and Albert C. Smith.

A Rare Parasitic Food Plant of the Southwest, by Frank A. Thackery and M. French Gilman.

The Mechanism of Organic Evolution, by Charles B. Davenport.

Extra Chromosomes, a Source of Variations in the Jimson Weed, by Albert F. Blakeslee.

The Age of the Human Race in the Light of Geology, by Stephen Richarz.

Elements of the Culture of the Circumpolar Zone, by W. G. Bogoras.

The Tell en-Nasbeh Excavations of 1929—a preliminary report, by William Frederic Badé.

Recent Progress in the Field of Old World Prehistory, by George Grant MacCurdy.

Ancient Seating Furniture in the Collections of the United States National Museum, by Walter Hough.

Aspects of Aboriginal Decorative Art in America Based on Specimens in the United States National Museum, by Herbert W. Krieger.

The Acclimatization of the White Race in the Tropics, by Robert de C. Ward.

The Eighth Wonder: The Holland Vehicular Tunnel, by Carl C. Gray and H. F. Hagen.

George Perkins Merrill, by Charles Schubert.

Jesse Walter Fewkes, by John R. Swanton and F. H. H. Roberts, jr.

FREER GALLERY OF ART PUBLICATIONS

Yaksas, Part II. By Ananda K. Coomaraswamy. May 19, 1931. 84 pp., 50 pls. (Publ. 3059.)

SPECIAL PUBLICATIONS

Explorations and Field Work of the Smithsonian Institution in 1930. March 25, 1931. 224 pp., 198 figs. (Publ. 3111.)

Classified List of Smithsonian Publications Available for Distribution, May 22, 1931. Compiled by Helen Munroe. May 22, 1931. 30 pp. (Publ. 3119.)

Brief Guide to the Smithsonian Institution. January 15, 1931. 79 pp.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

Through the retirement of Dr. Marcus Benjamin on January 31, 1931, the editorial work of the National Museum devolved upon W. P. True until Paul H. Oehser was appointed on April 15, 1931, to fill the vacancy. During the year ending June 30, 1931, the Museum published 1 annual report, 1 volume of proceedings, 3 complete bulletins, 1 part of a bulletin, 1 complete volume, 1 part and 1 index in the series Contributions from the United States National Herbarium, and 40 separates from the proceedings.

The issues of the bulletin were as follows:

Bulletin 82. A Monograph of the Existing Crinoids. Volume 1—The Comatulids. Part 3. Superfamily Comasterida. By Austin Hobart Clark.

Bulletin 100. Contributions to the Biology of the Philippine Archipelago and Adjacent Regions.

Volume 11. The Fishes of the Families Pseudochromidae, Lobotidae, Pempheridae, Priacanthidae, Lutjanidae, Pomadasyidae, and Teraponidae, Collected by the United States Bureau of Fisheries Steamer *Albatross*, Chiefly in Philippine Seas and Adjacent Waters. By Henry W. Fowler.

Bulletin 154. A Study of the Teiid Lizards of the Genus Cnemidophorus, with Special Reference to Their Phylogenetic Relationships. By Charles E. Burt.

Bulletin 155. The Birds of Haiti and the Dominican Republic. By Alexander Wetmore and Bradshaw H. Swales.

The issues of the contributions from the United States National Herbarium were as follows:

Volume 24. Title Page, Preface, Contents, List of Illustrations, and Index to Volume 24, Contributions from the United States National Herbarium.

Volume 24. Plant Studies—Chiefly Tropical American.

Volume 26, part 6. Asiatic Pteridophyta collected by Joseph F. Rock 1920–1924. By Carl Christensen.

Of the separates from the proceedings, 11 were from volume 77, 23 from volume 78, and 6 from volume 79.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the bureau has continued under the direction of the editor, Stanley Searles. During the year two annual reports and three bulletins were issued, as follows:

Forty-fifth Annual Report. Accompanying papers: The Salishan Tribes of the Western Plateaus (Teit, edited by Boas); Tattooing and Face and Body Painting of the Thompson Indians, British Columbia (Teit, edited by Boas); The Ethnobotany of the Thompson Indians of British Columbia (Steedman); The Osage Tribe; Rite of the Wa-xo-be (LaFlesche). vii+857 pp., 29 pls., 47 figs.

Forty-sixth Annual Report. Accompanying papers: Anthropological Survey in Alaska (Hrdlička); Report to the Honorable Isaac S. Stevens, Governor of Washington Territory, on the Indian Tribes of the Upper Missouri (Denig, edited by Hewitt), vii+654 pp., 80 pls., 35 figs.

Bulletin 96. Early Pueblo Ruins in the Piedra District, Southwestern Colorado (Roberts). ix+190 pp., 55 pls., 40 figs.

Bulletin 97. The Kamia of Imperial Valley (Gifford). vii+94 pp., 2 pls., 4 figs.

Bulletin 100. The Ruins at Kiatuthlanna, Eastern Arizona (Roberts). viii+195 pp., 47 pls., 31 figs.

Publications in press at the close of the fiscal year were as follows:

Forty-seventh Annual Report. The Acoma Indians (White); Isleta, New Mexico (Parsons); Introduction to Zuñi Ceremonialism, and Zuñi Origin Myths (Bunzel); Zuñi Ritual Poetry (Bunzel); Zuñi Katcinas (Bunzel).

Bulletin 94. Tobacco Among the Karuk Indians of California (Harrington).

Bulletin 98. Tales of the Cochiti Indians (Benedict).

Bulletin 99. Cherokee Sacred Formulas and Medicinal Prescriptions (Mooney and Olbrechts).

Bulletin 101. Indian Blankets of the North Pacific Coast (Kissell).

Bulletin 102. Menominee Music (Densmore).

Bulletin 103. Source Material for the Social and Ceremonial Life of the Choctaw Indians (Swanton).

Bulletin 104. A Survey of the Ruins in the Region of Flagstaff, Arizona (Colton).

Bulletin 105. Notes on the Wâpanōwiweni (Michelson).

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

The annual reports for 1927 and 1928 (1 volume), and for 1929, were issued during the year, and also the supplemental volume to the report for 1927. The annual report for 1930, Volume III, and the supplemental volume to the report for 1928, were in press at the close of the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Thirty-third Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with the law, November 12, 1930.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian report to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1932, totals $104,000, allotted as follows:

Annual report to the Congress of the Board of Regents of the Smithsonian Institution	$12, 000
National Museum	50, 000
Bureau of American Ethnology	28, 300
National Gallery of Art	500
International Exchanges	300
International Catalogue of Scientific Literature	100
National Zoological Park	300
Astrophysical Observatory	500
Annual report of the American Historical Association	12, 000

SMITHSONIAN ADVISORY COMMITTEE ON PRINTING AND PUBLICATION

The editor continued to serve as secretary to the Smithsonian advisory committee on printing and publication until March 1, 1931, when the committee was dissolved by the reorganization of the editorial department of the Institution mentioned earlier in this report. Four meetings were held and 88 manuscripts were acted upon. The membership at the last meeting was as follows: Dr. Leonhard Stejneger, head curator of biology, National Museum, chairman; Dr. William M. Mann, director, National Zoological Park; M. W. Stirling, chief, Bureau of American Ethnology; Dr. R. S. Bassler, head curator of geology, National Museum; W. P. True, editor of the Institution, secretary; and Stanley Searles, editor of the Bureau of American Ethnology.

Since the editorial reorganization, manuscripts come directly to the editor of the Smithsonian Institution with the recommendation of the head of the publishing bureau, who has taken expert advice as to their merit and suitability for printing.

Respectfully submitted.

W. P. True, *Editor*.

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDED JUNE 30, 1931

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution:

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8 shillings 6 pence—$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015 which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of		$550, 000. 00
Since the original bequest the Institution has received gifts from various sources, chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution, to the amount of		260, 607. 39
Total capital gain from investment of savings from income		219, 762. 52
Total capital gain from sale of securities, stock dividends, etc		15, 595. 42
Total endowment for general purposes as per last report	$1,033,789. 85	
Capital gain from gifts during the year ended June 30, 1931	5. 00	
Capital gain from stock dividends, sale of securities, etc	204. 07	
Capital gain from sale of Smithsonian Scientific Series	11, 966. 41	
Present total endowment for general purposes	1, 045, 965. 33	1, 045, 965. 33

The Institution holds also a number of endowment gifts the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Arthur, James, fund, income for investigations and study of sun and lecture on the sun	$52, 595. 02
Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States	65, 887. 12
Baird, Lucy H., fund, for creating a memorial to Secretary Baird	2, 176. 54
Barstow, Frederic D., fund, for purchase of animals for the Zoological Park	1, 000. 28

Canfield collection fund, for increase and care of the Canfield collection of minerals		$50, 299. 78
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera		9, 503. 63
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks		37, 032. 20
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air		100, 000. 00
Hughes, Bruce, fund, to found Hughes alcove		17, 963. 17
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of and benefit of the National Gallery of Art		22, 744. 20
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection		3, 175. 03
Poore, Lucy T., and George W., fund, for general use of the Institution when principal amounts to the sum of $250,000		62, 036. 08
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis		25, 067. 21
Roebling fund, for care, improvement, and increase of Roebling collection of minerals		158, 706. 78
Springer, Frank, fund, for care, etc., of Springer collection and library		30, 000. 00
Walcott, Charles D. and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof		12, 915. 80
Younger, Helen Walcott, fund, held in trust		49, 812. 50
Zerbee, Frances Brincklé, fund, for endowment of aquaria		1, 000. 85
Total endowment for specific purposes other than Freer endowment as per last report	$636, 792. 55	
Capital gain from new funds, additional gifts, etc	57, 187. 20	
Capital gain from investment of savings from income during the year ended June 30, 1931	7, 822. 07	
Capital gain from stock dividends, sale of securities, etc., during the year ended June 30, 1931	114. 37	
Excluding Freer endowment, total present endowment for specific purposes	701, 916. 19	701, 916. 19

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, Mich., gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally, in his will, probated November 6, 1919, he provided stock and securities to the estimated value of $1,958,591.42 as an endowment fund for the operation of the gallery. In view of the importance and special nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

Original endowment for expenses of gallery		$1, 958, 591. 42
Total capital gain from investments of savings from income		416, 079. 26
Total capital gain from stock dividends, sale, etc., of securities		2, 993, 040. 83
Total capital as per last report	$5, 300, 929. 50	
Capital gain from investment of savings from income during the year ended June 30, 1931	5, 697. 95	
Capital gain from stock dividends, sale of securities, etc., during the year ended June 30, 1931	61, 084. 06	
Total Freer endowment for specific purposes	5, 367, 711. 51	5, 367, 711. 51

SUMMARY

Invested endowment for general purposes	1, 045, 965. 33
Invested endowment for specific purposes other than Freer endowment	701, 916. 19
Total invested endowment other than Freer endowment	1, 747, 881. 52
Freer invested endowment for specific purposes	5, 367, 711. 51
Total invested endowment for all purposes	7, 115, 593. 03

CLASSIFICATION OF INVESTMENTS

Deposited in the United States Treasury at 6 per cent per annum as authorized in the United States Revised Statutes, section 5591		1, 000, 000. 00
Investments other than Freer endowment:		
Bonds	$266, 688. 61	
Stocks	465, 308. 45	
Real estate first-mortgage notes	11, 500. 00	
Uninvested capital	4, 384. 46	
		747, 881. 52
Total investments other than Freer endowment		1, 747, 881. 52
Investments of Freer endowment:		
Bonds	$2, 651, 049. 48	
Stocks	2, 634, 982. 42	
Real estate first-mortgage notes	67, 000. 00	
Uninvested capital	14, 679. 61	
		5, 367, 711. 51
Total investments		7, 115, 593. 03

INCOME FROM INVESTMENTS DURING THE YEAR ENDED JUNE 30, 1931

		Corresponding figures for year ending June 30, 1930
From $1,000,000 deposited in United States Treasury at 6 per cent	$60, 000. 00	$60, 000. 00
From funds invested in stocks, bonds, etc., other than Freer endowment, including gain from sales, etc., of securities, stock dividends, etc	33, 334. 96	34, 624. 40
Total income other than Freer endowment	93, 334. 96	94, 624. 40
FREER ENDOWMENT		
From funds invested in stocks, bonds, etc., including gain from sales, etc., of securities, stock dividends, etc	372, 461. 46	334, 936. 39
Total income from investments	465, 796. 42	429, 560. 79

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR [1]

Cash balance on hand June 30, 1930		$214, 870. 17
Receipts:		
Cash from invested endowments and from miscellaneous sources for general use of the Institution	$74, 306. 66	
Cash for increase of endowments for specific use	81, 559. 89	
Cash gifts for increase of endowments for general use	5. 00	
Cash gifts, etc., for specific use (not to be invested)	90, 064. 79	
Cash received as royalties from sales of Smithsonian Scientific Series	17, 222. 53	
Cash gain from sale, etc., of securities (to be invested)	317. 09	
Cash income from endowments for specific use other than Freer endowment, and from miscellaneous sources (including refund of temporary advances)	62, 528. 93	
Cash capital from sale, call of securities, etc. (to be reinvested)	63, 998. 50	
Total receipts other than Freer endowment		390, 003. 39
Cash receipts from Freer endowment—income from investments	$311, 377. 40	
Gain from sale, etc., of securities (to be invested)	110, 334. 34	
Cash capital from sale, call of securities, etc. (to be reinvested)	1, 160, 106. 80	
		1, 581, 818. 54
Total		2, 186, 692. 10

[1] This statement does not include Government appropriations under the administrative charge of the Institution.

Disbursements:		
From funds for general work of the Institution—		
Buildings, care, repairs and alterations	$3, 246. 94	
Furniture and fixtures	700. 49	
General administration [2]	23, 091. 60	
Library	3, 163. 31	
Publications (comprising preparation, printing, and distribution)	23, 690. 54	
Researches and explorations	21, 960. 16	
International exchanges	4, 982. 01	
		$80, 835. 05
From funds for specific use other than Freer endowment—		
Investments made from gifts, from gain from sales, etc., of securities and from saving on income	78, 074. 41	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances)	185, 547. 69	
Cash capital from sale, call of securities, etc., reinvested	59, 873. 34	
		323, 495. 44
From Freer endowment—		
Operating expenses of gallery, salaries, purchase of art objects, field expenses, etc	289, 883. 42	
Investments made from gain from sale, etc., of securities and from income	110, 128. 62	
Cash capital from sale, call of securities, etc., reinvested	1, 158, 127. 73	
		1, 558, 139. 77
Balance June 30, 1931		224, 221. 84
Total		2, 186, 692. 10

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general endowment—		
Publications	$23, 690. 54	
Researches and explorations	21, 960. 16	
		$45, 650. 70
Expenditures from funds devoted to specific purposes:		
Researches and explorations	88, 030. 83	
Care, increase, and study of special collections	18, 104. 14	
Publications	22, 264. 56	
		128, 399. 53
Total		174, 050. 23

[2] This includes salaries of the Secretary and certain others.

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Table showing growth of endowment funds of the Smithsonian Institution

Year	Endowment for general work of the Institution, being original Smithson bequest, gifts from other sources, and invested savings of income	Endowment for specific researches, etc., including invested savings of income	Freer gift for construction of Freer Gallery of Art Building	Freer bequest for operation of Freer Gallery of Art, including salaries, care, etc.
1846–1891	[1] $702, 000. 00			
1892	802, 000. 00	$101, 000. 00		
1893–1894	852, 000. 00	101, 000. 00		
1895–1903	877, 000. 00	102, 000. 00		
1904–1913	885, 807. 58	111, 692. 42		
1914	885, 807. 58	116, 692. 42		
1915	886, 084. 02	143, 515. 98		
1916	887, 607. 08	160, 527. 30	$1, 000, 000. 00	
1917	887, 830. 00	164, 304. 38		
1918	[2] 883, 867. 00	176, 157. 38		
1919	884, 305. 00	190, 489. 38		
1920	884, 747. 00	198, 149. 02		
1921	884, 933. 74	272, 538. 31	[3] 367, 072. 04	$1, 253, 004. 75
1922	886, 107. 14	291, 858. 14		1, 842, 144. 75
1923	886, 246. 14	306, 524. 14		[4] 3, 296, 574. 75
1924	886, 373. 31	319, 973. 19		3, 401, 355. 42
1925	886, 769. 73	338, 136. 77		3, 459, 705. 34
1926	886, 830. 13	342, 876. 37		3, 714, 361. 23
1927	886, 877. 79	498, 401. 96		4, 171, 880. 61
1928	929, 068. 21	665, 233. 29		4, 268, 244. 26
1929	[5] 1, 022, 385. 75	626, 003. 70		5, 236, 054. 02
1930	1, 033, 789. 85	636, 792. 55		5, 300, 929. 50
1931	1, 045, 965. 33	701, 916. 19		5, 367, 711. 51

[1] Original endowment plus income from savings during these years.
[2] Loss on account of bonds reduced on books from par to market value.
[3] Cash from sale of 2,000 shares of Parke, Davis & Co. stock, including dividends, and interest on gift of $1,000,000.
[4] In this year Parke, Davis & Co. declared 100 per cent stock dividend.
[5] Increase largely from funds transferred from specific endowment column and income released for general work of the Institution.

BALANCE SHEET OF THE SMITHSONIAN INSTITUTION JUNE 30, 1931

ASSETS

Stocks and bonds at acquirement value:		
Consolidated fund	$663, 684. 56	
Freer bequest	5, 353, 031. 90	
Springer fund	30, 000. 00	
Younger fund	49, 812. 50	
		$6, 096, 528. 96
U. S. Treasury deposit		1, 000, 000. 00
Miscellaneous, principally funds advanced for printing publications, and field expenses (to be repaid)		51, 388. 04
Cash:		
Funds in U. S. Treasury and in banks	$224, 221. 84	
In office safe for cash transactions	1, 300. 00	
		225, 521. 84
Total		7, 373, 438. 84

LIABILITIES

Freer bequest, capital accounts:		
Court and grounds fund	$604, 625. 07	
Court and grounds maintenance fund	151, 331. 11	
Curator fund	609, 329. 43	
Residuary estate fund	4, 002, 425. 90	
		5, 367, 711. 51
CAPITAL ACCOUNTS		
Arthur, James, fund		52, 595. 02
Bacon fund		65, 887. 12
Baird fund		2, 176. 54
Barstow, Frederic D., fund		1, 000. 28
Canfield collection fund		50, 299. 78
Casey, Thomas Lincoln, fund		9, 503. 63
Chamberlain fund		37, 032. 20
Hodgkins fund, specific		100, 000. 00
Hughes, Bruce, fund		17, 963. 17
Myer fund		22, 744. 20
Pell fund		3, 175. 03
Poore fund		62, 036. 08
Reid fund		25, 067. 21
Roebling collection fund		158, 706. 78
Smithsonian unrestricted fund		1, 045, 965. 33
Springer fund		30, 000. 00
Walcott research fund		12, 915. 80
Younger fund		49, 812. 50
Zerbee, Frances Brincklé, fund		1, 000. 85
CURRENT ACCOUNTS		
Freer bequest residuary estate fund		117, 836. 58
Springer fund		1, 595. 88
Younger fund		217. 50
Miscellaneous accounts held by the Institution for the most part for specific use		138, 195. 85
Total		7, 373, 438. 84

During the year, the Institution received as gifts a total of approximately $145,000, which included donations for specific uses not to be invested, for increase of endowments for specific purposes, and a small sum for the increase of the general endowment fund.

All payments are made by check, signed by the Secretary of the Institution, on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The practice of investing temporarily idle funds in time deposits has proven satisfactory. During the year the interest derived from this source has resulted in a total of $5,026.75.

The foregoing report relates only to the private funds of the Smithsonian Institution. The following is a statement of the congressional appropriations for the past 10 years for the support of the several governmental branches under the administrative control of the Institution and of appropriations for other special purposes during that period.

Table showing the appropriations made by Congress during the last 10 years, intrusted to the care of the Smithsonian Institution

Year	International exchanges	American ethnology	Cooperative ethnological researches	International Catalogue of Scientific Literature	Astrophysical Observatory	Increase of compensation	National Museum	Gellatly art collection
1922	$50,000.00	$46,000.00		$7,500.00	$15,500.00		$419,138.86	
1923	45,000.00	44,000.00		7,500.00	15,500.00	$109,044.00	418,120.00	
1924	43,000.00	44,000.00		7,500.00	15,500.00	112,704.00	415,000.00	
1925	49,550.00	57,160.00		8,861.66	21,580.00		547,292.00	
1926	46,260.00	57,160.00		8,000.00	[1] 31,180.00		554,392.00	
1927	46,260.00	57,160.00		7,500.00	31,180.00		565,820.00	
1928	46,855.00	58,720.00		7,260.00	32,060.00		606,960.00	
1929	50,355.00	65,800.00	$20,000.00	7,885.00	36,630.00		701,524.00	
1930 [2]	51,297.00	68,800.00		7,885.00	36,720.00		717,014.00	$21,000.00
1931	52,810.00	70,840.00		8,145.00	37,560.00		[8] 793,894.00	20,000.00

Year	Safeguarding dome of Natural History Building	National Zoological Park	Additional for Zoological Park	National Gallery of Art	Printing and binding	Additional assistant secretary	Salaries and expenses	Additional fire protection
1922		$125,000.00	[3] $80,000.00	$15,000.00				
1923		125,000.00	[3] 2,500.00	15,000.00	$77,400.00			
1924		125,000.00		16,000.00	77,400.00			
1925		151,487.00		20,158.00	90,000.00	$6,000.00		$8,500.00
1926		157,000.00		21,028.00	90,000.00	6,000.00		
1927		173,199.00		29,381.00	90,000.00	6,000.00		
1928		175,000.00	[4] 25,000.00	30,356.00	90,000.00	[5] 7,500.00		
1929	[6] $80,000.00	195,550.00	[4] 30,000.00	35,273.00	95,000.00		$35,804.00	
1930		203,000.00	[7] 222,000.00	34,853.00	95,000.00		36,004.00	
1931		220,520.00	[9] 28,000.00	45,218.00	99,000.00		38,804.00	

[1] Increase in appropriation due to Government assuming part of the expenses of the Chilean Station, which up to this time had been supported by private funds of the Smithsonian Institution.
[2] Increases over former figures due to passage of Welch Act after printing of last report.
[3] Additional land.
[4] Building for birds.
[5] After 1928 this item is included in appropriation for salaries and expenses.
[6] Work done by Supervising Architect and funds disbursed by United States Treasury.
[7] Building for reptiles, etc., $220,000; gates for south boundary of park, $2,000.
[8] Includes plans for additions to Natural History Building, $10,000.
[9] Additional for building for reptiles.

The report of the audit of the Smithsonian private funds is printed below.

OCTOBER 7, 1931.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1931, and certify the balance of cash on hand June 30, 1931, to be $225,521.84.

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found then in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1931, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet in our opinion correctly presents the financial condition of the Institution as of June 30, 1931.

WILLIAM L. YAEGER & CO.
WILLIAM L. YAEGER
Certified Public Accountant.

Respectfully submitted.

FREDERIC A. DELANO,
R. WALTON MOORE,
JOHN C. MERRIAM,
Executive Committee.

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE FISCAL YEAR ENDED JUNE 30, 1931

ANNUAL MEETING, DECEMBER 11, 1930

Present: Chief Justice Charles Evans Hughes, chancellor, in the chair, Vice President Charles Curtis, Senator Joseph T. Robinson, Representative Albert Johnson, Representative R. Walton Moore, Representative Robert Luce, Frederic A. Delano, Dr. John C. Merriam, and the secretary, Dr. C. G. Abbot. Dr. Alexander Wetmore, assistant secretary was also present.

At the previous annual meeting of the board, the Langley gold medal for aerodromics was awarded to Charles Matthews Manly (posthumously) and to Admiral Richard Evelyn Byrd. At the present meeting the actual presentation of the medal was made to Mr. Manly through his son Charles W. Manly. The chancellor made the address of presentation, and Mr. Manly accepted the medal on behalf of his family. Extracts from the remarks of the chancellor and Mr. Manly will be found in the Report of the Secretary of the Smithsonian Institution for 1931.

Mr. Delano, chairman of the executive committee, offered the following customary resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1932, be appropriated for the service of the Institution, to be expended by the secretary, with the advice of the executive committee, with full discretion on the part of the secretary as to items.

The secretary presented his printed report for the fiscal year ending June 30, 1930. He stated that the publications of the Institution during the fiscal year 1930 totaled 95 volumes and pamphlets, of which 38 were issued by the Institution proper, 51 by the National Museum, and 6 by the Bureau of American Ethnology. Under the Institution's policy of world-wide distribution, 168,163 copies of its publications were sent out to organizations and individuals, for the most part free.

Mr. Delano submitted the printed report showing the financial affairs of the Institution for the fiscal year ending June 30, 1930.

The annual report of the National Gallery of Art Commission was presented and accepted, and the following resolution was adopted:

Resolved, That the Board of Regents of the Smithsonian Institution hereby approves the recommendation of the National Gallery of Art Commission that

Gari Melchers, Herbert Adams, and Charles Moore be reelected as members of the commission for the ensuing term of four years, their present terms having expired.

The matter of the purchase and erection of the Bush-Brown statue, The Indian Buffalo Hunt, was brought up, and on motion it was resolved to refer it to the executive committee with power to act.

The secretary then presented a supplementary report, mentioning a number of special events and activities during the year. He spoke particularly of the support by the Research Corporation of the work of the Division of Radiation and Organisms; of continued generous gifts by John A. Roebling to aid the Institution's solar-radiation researches; of additions by Mr. Gellatly to the very valuable art collection previously given to the Institution; of the considerable sum already received in royalties from the sale of the Smithsonian Scientific Series; of the completion of the series North American Wild Flowers, by Mary Vaux Walcott; and of the important discoveries in European archives of early manuscripts relating to the Americas by Dr. C. U. Clark, working under a grant from Ambassador Charles G. Dawes.

At the request of the Secretary, Doctor Wetmore described certain of the year's explorations under the Institution. Doctor Wetmore also spoke of the status of the proposed additional wings on each side of the Museum Building.

It was announced that a telegram had been received from Admiral Byrd fixing March 27, 1931, as a convenient date for the presentation of the Langley gold medal awarded to him at the last meeting of the board.

REGULAR MEETING OF FEBRUARY 12, 1931

Present: Chief Justice Charles E. Hughes, chancellor in the chair, Senator Joseph T. Robinson, Senator Claude A. Swanson, Representative Robert Luce, Frederic A. Delano, and the secretary, Dr. C. G. Abbot. Dr. Alexander Wetmore, assistant secretary, was also present.

The secretary mentioned, with explanatory remarks, recent financial receipts by gifts and otherwise, including royalties from the Smithsonian Scientific Series; a grant from the Research Corporation to promote studies of radiation and plant growth; the final payment of the Bruce Hughes fund to establish the Bruce Hughes alcove; the Frederic D. Barstow fund for purchase of living animals, National Zoological Park; the Zerbee fund for an aquarium as a memorial to Frances Brinklé Zerbee, National Zoological Park; and a gift from Otto T. Mallery for special archeological work under the Bureau of American Ethnology. He also announced a proposed bequest by a citizen of New York State for the encouragement and reward of scientific research.

Other matters of importance to the work of the Institution were then brought before the board for discussion.

On March 27, 1931, as noted above, the Langley gold medal was presented to Admiral Byrd in the main hall of the Smithsonian Building in the presence of members of the Board of Regents and other distinguished guests. The presentation was made by Chancellor Charles E. Hughes; Admiral Byrd, in accepting the medal, spoke of his appreciation of the award and of his great respect for the work of Professor Langley. Further details of the presentation will be found in the Report of the Secretary of the Smithsonian Institution for 1931.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1931

ADVERTISEMENT

The object of the General Appendix to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though, not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1931.

TWENTY-FIVE YEARS' STUDY OF SOLAR RADIATION

By C. G. Abbot

Secretary, Smithsonian Institution

[With 3 plates]

INFRA-RED SOLAR SPECTRUM MAP AND THE DISPERSION OF ROCK SALT

Thirty years ago at Washington, under Dr. S. P. Langley's direction, F. E. Fowle and I completed a map of the sun's invisible infra-red spectrum. Our map extended from Fraunhofer's "A," at wave length 0.76 micron, to a point far down in the infra-red of wave length 5.3 microns. We felt out and recorded the invisible spectrum lines with the photographic registering spectrobolometer. Langley used to say that in his use of the spectrobolometer on Mount Whitney in 1881 the indicator often raced across the scale 1 meter long in a minute. We had so far tamed this wild creature by the year 1900 that the indicator seldom wandered a centimeter in an hour. Nevertheless, that delicate electrical thermometer, the bolometer, was then so sensitive that a deflection of a millimeter on the photographic recording scale corresponded to a temperature change of only 0.000004° Centigrade.

The infra-red solar spectrum map which we made between 1895 and 1900 contained 740 lines. Their positions were recognized as cooled bits of the spectrum by the fine metallic sensitive thread of the bolometer. No doubt a considerable number of those 740 lines were spurious, for every tremor of the earth and every accidental temperature change added its unwelcome deflections to the record. We eliminated the false and preserved the true, as well as we were able, by comparing many independent records. To fix the wave lengths we made a special investigation of the dispersion of rock salt prisms. Paschem repeated it later. His results agreed generally with ours in the fifth decimal place of the refractive index of rock salt.

In 1928 H. B. Freeman and I went over a part of this infra-red spectrum again on Mount Wilson. We used three times as great dispersion as in the old work at Washington. In the region from 0.76 to 1.8 microns we obtained about 1,300 lines where formerly we found about 550. Dr. H. D. Babcock, of the Mount Wilson Observatory, has done much photographic work covering a part of this upper

infra-red solar spectrum region. He finds that our old bolometric work of 1900 deserved a good word as to the accuracy of the wave lengths and as to the general reality of the lines found and that our new work added to it some really useful detail.

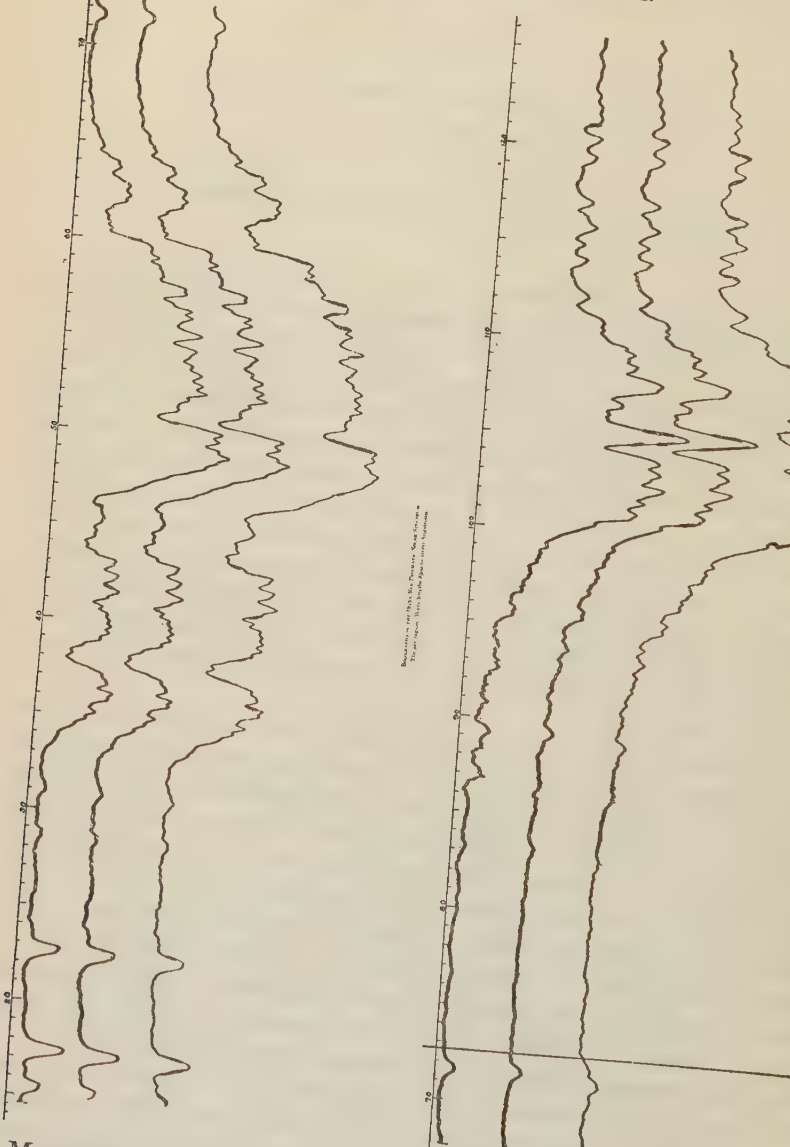

FIGURE 1.—Portions of solar energy curves of 1928 showing line and band absorption of solar and terrestrial atmospheric gases and vapors in the invisible infra-red spectrum

Many of the infra-red spectrum lines are now identified by investigators as due to specific elements in the gases of the sun, others to vapors in the earth's atmosphere. There were two mystery bands in the spectrum called ω_1 and ω_2 of wave length about 2.0 microns, which long puzzled us because we knew they were atmospheric but

surely not due to water vapor. I have seen quite recently some beautiful absorption spectra by H. J. Unger, of the University of Oregon, which prove that ω_1 and ω_2 are really caused by terrestrial carbonic acid gas.

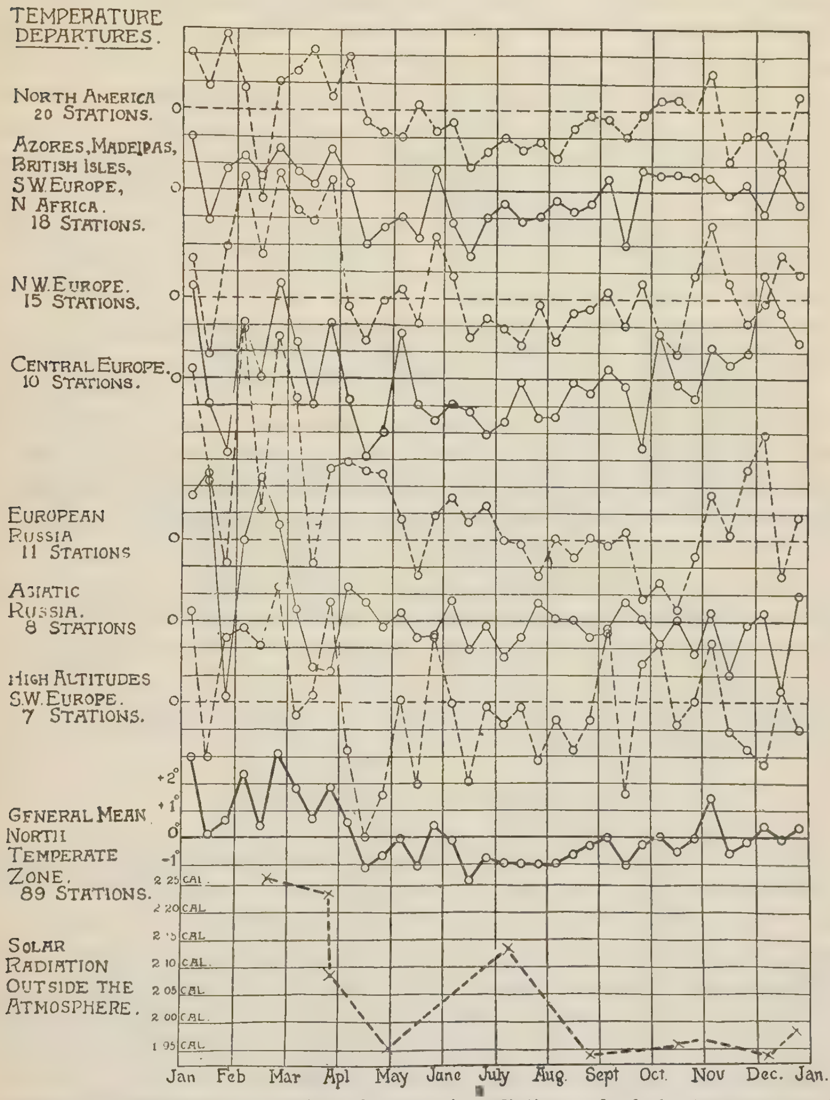

FIGURE 2.—Simultaneous lowering of the sun's radiation and of the temperature of the earth's northern hemisphere as observed in March, 1903

SOLAR-CONSTANT WORK BEGUN IN 1902

Doctor Langley was deeply interested in the value of the solar constant of radiation, which is the measure of the intensity of the sun's rays as they are in free space at the earth's mean solar distance.

Hence, in the year 1902, we began a solar-constant research destined to be a very long one. At that time solar-constant values ranging from 1.76 to 4.0 calories were given in standard textbooks.

Our earliest Washington work raised a question which has engrossed us for over 25 years. Our results of 1902, 1903, and 1904 seemed to indicate that the sun's output of radiation decreased rather suddenly in March, 1903, by about 10 per cent, and continued low thereafter. We should certainly have attributed this to obscure error if the temperature of the entire north temperate land area of the world had not shown a decrease at the same time. We think now that we were misled by an atmospheric turbidity caused by a volcanic eruption in southern Mexico. At all events, we began then to suspect that the sun is a variable star and that its fluctuations produce important weather changes. I hope now, after more than 25 years of investigation, to present evidence to convince you that such is really the case.

The determination of the solar constant of radiation involves two principal parts. First, the exact measurement of the intensity of solar radiation as received at the observing station; second, the exact estimation of the loss which the rays suffer in traversing the atmosphere. The first requirement involves an accurate pyrheliometer. The second requirement involves exact measurements of the atmospheric transmission coefficients for all important solar spectrum rays. Besides this, there must be estimates of the relative transmissibility of the spectral rays in the optical apparatus, and of the atmospheric transmission of those feeble parts of the solar spectrum lying in the ultra-violet and the infra-red beyond the limits of the spectrum region usually observed.

THE SILVER-DISK PYRHELIOMETER

When we began solar-constant work in 1902, the beautiful electrical compensation pyrheliometer of Knut Ångström was already available, though not fully perfected. Following, however, in Langley's path, we developed for our use the older form of pyrheliometer of Pouillet and Tyndall. With us it became in 1910 the well-known silver-disk pyrheliometer, of which the Smithsonian Institution has since furnished more than 60 standardized copies at cost to solar-radiation observers in all parts of the world.

The silver-disk pyrheliometer, though simple, effective, and accurate, and capable of maintaining a constant scale of readings for many years, is not an independent standard. Means are required to reduce its scale to true calories per square centimeter per minute. For this purpose we developed the standard water-flow and water-

stir pyrheliometers. Our findings with these instruments are expressed as the so-called "Smithsonian Pyrheliometry of 1913," which has been accepted quite generally as the standard pyrheliometric scale of the world. It differs by about 3 per cent from the Ångström scale. Experiments by independent methods are now in progress in Germany to further establish the true pyrheliometric scale.

THE STANDARD WATER-FLOW PYRHELIOMETER

In the standard water-flow pyrheliometer, the solar rays admitted by a measured aperture are chiefly absorbed on a hollow blackened metallic cone at the rear of a test-tube-shaped blackened metallic chamber. A measured current of water continually removes the heat produced on the cone and on the inner walls of the chamber.

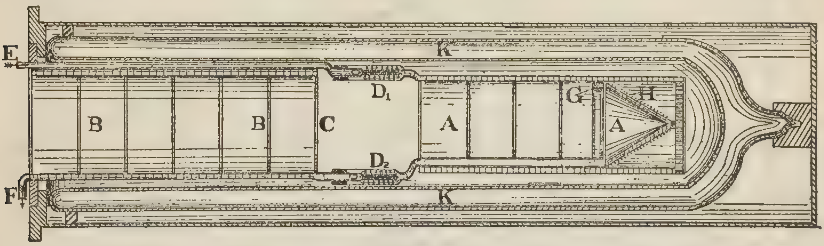

FIGURE 3.—Diagram of the water-flow pyrheliometer

A A, ray absorber; B B, vestibule; C, measured aperture; D_1 D_2, electrical thermometer; E F, entering and emerging water flow; G H, electrical test coils; K K, Dewar vacuum flask

An electrical thermometer measures the rise of temperature thus produced in the water current. For test purposes, known quantities of heat may be introduced at the cone by measured electrical currents. The accuracy of the instrument, which is very satisfactory, is measured by the equivalence of heat introduced and heat found. The instrument is represented in Figure 3.

THE FUNDAMENTAL SOLAR-CONSTANT METHOD

The fundamental solar-constant method as worked out by Langley involves determining the intensity of all parts of the solar spectrum repeatedly on a day of unchanging clearness, so as to disclose the increase of intensity of each spectral ray which occurs as the sun mounts higher and higher. For a ray of homogeneous wave length, the intensity is connected with the length of path in the atmosphere by the exponential formula of Lambert and Bouguer:

$$e=e_0a^m; \text{ or } \log e=m \log a+\log e_0$$

Here e is the observed intensity; e_0 that which would be observed outside the atmosphere; a is the fraction transmitted with vertical sun; and m is the

air mass, or in other words the ratio of the length of path of the ray in the atmosphere to that obtaining with vertical sun. In its logarithmic form the

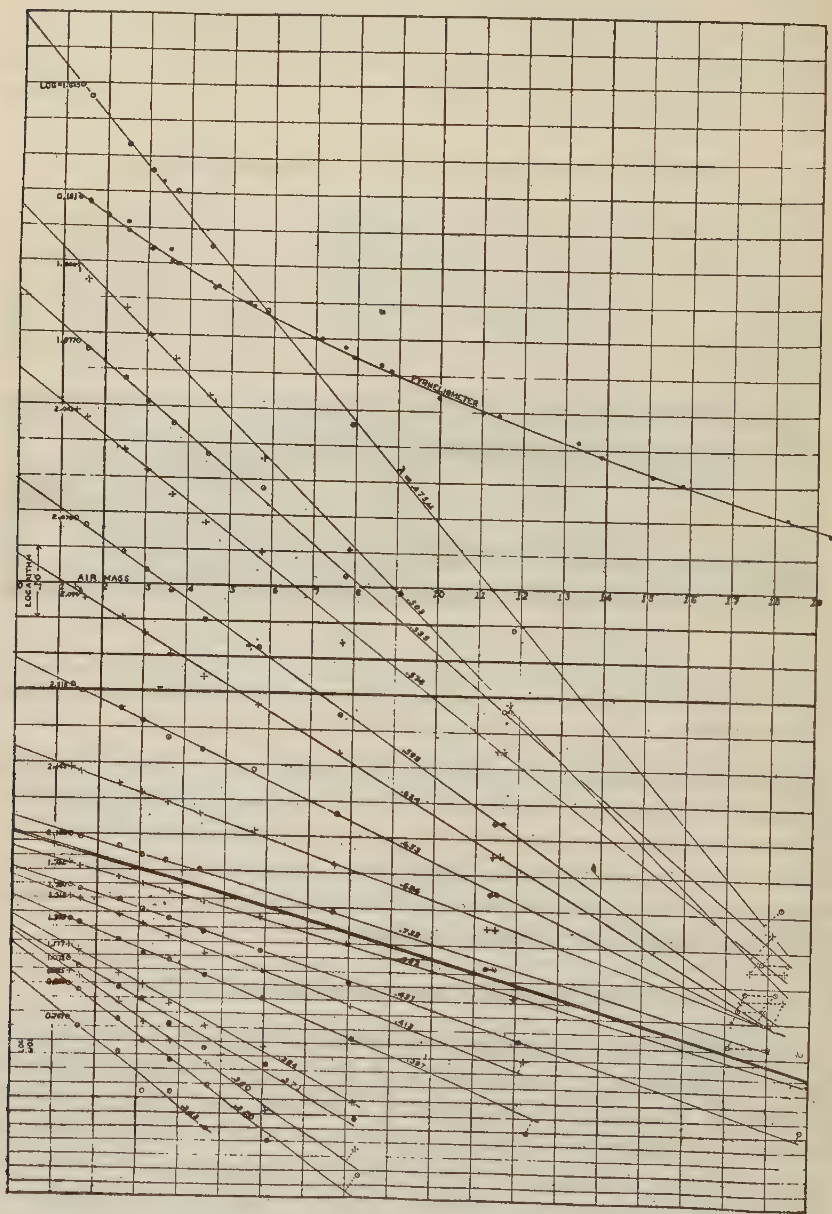

FIGURE 4.—Logarithmic curves indicating the atmospheric transmission at Mount Wilson in many wave lengths

formula is the equation of the straight line. We find it satisfactorily exact on many days at our excellent high-altitude stations in California, Chile, and South West Africa.

Since the formula holds strictly only for rays of homogeneous wave length, we require spectrum measurements. If from a series of bolographs of the solar spectrum, in which the partial transmissibility of the optical instruments has been allowed for, we determine atmospheric transmission coefficients for about 40 selected wave lengths between 0.34 and 2.5 microns, we can compute the intensity which each of these rays would represent if observed outside the atmosphere. This determines the sun's spectrum energy curve as it would be observed in free space. If we compute the area included under the curve thus determined, and divide it by the area included by the curve observed by the spectrobolometer, the quotient is the factor by which we must multiply the total intensity of the solar beam as measured by the pyrheliometer to give the intensity which the pyrheliometer would have read if in free space. Correcting the result to mean solar distance, we have the solar constant of radiation.

TRANSMISSIBILITY OF OPTICAL APPARATUS

As required for solar-constant determinations, we have made many measurements of the relative transmissibility of our optical instruments for the different spectral rays. Our procedure involves two spectroscopes, of which the auxiliary one delivers its spectrum upon the slit of the main one used for the bolographic work. Under these circumstances, we measure with the bolometer the intensity of many spectral rays both before and after they traverse the main spectroscope. Their relative transmissibility appears in the ratios of these measurements.

WAVE-LENGTH DISTRIBUTION OF SOLAR RADIATION, AND THE SUN'S EFFECTIVE TEMPERATURE

Such determinations of transmission in the optical train, together with the determinations of transmission in the atmosphere, enabled us to represent and tabulate the distribution of energy in the solar spectrum as it is outside our atmosphere. Our best results in this line were published in 1923 in a paper entitled "The distribution of energy in the spectra of the sun and stars."[1] They have been of use to other investigators for various purposes.

If we assume that the sun is approximately a perfect radiator, our work on the solar constant yields three methods of estimating his effective temperatures: First, from the spectral position of maximum intensity. Second, from the general form of the curve of distribution of energy in the spectrum. Third, from the sun's distance and diameter combined with the value of the solar constant of radiation.

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[1] Smithsonian Misc. Coll., vol. 74, No. 7.

These methods yield absolute centigrade temperatures as follows: 6,170°; 6,200°; 5,750°. The discrepancy is rather wide, but is, I think,

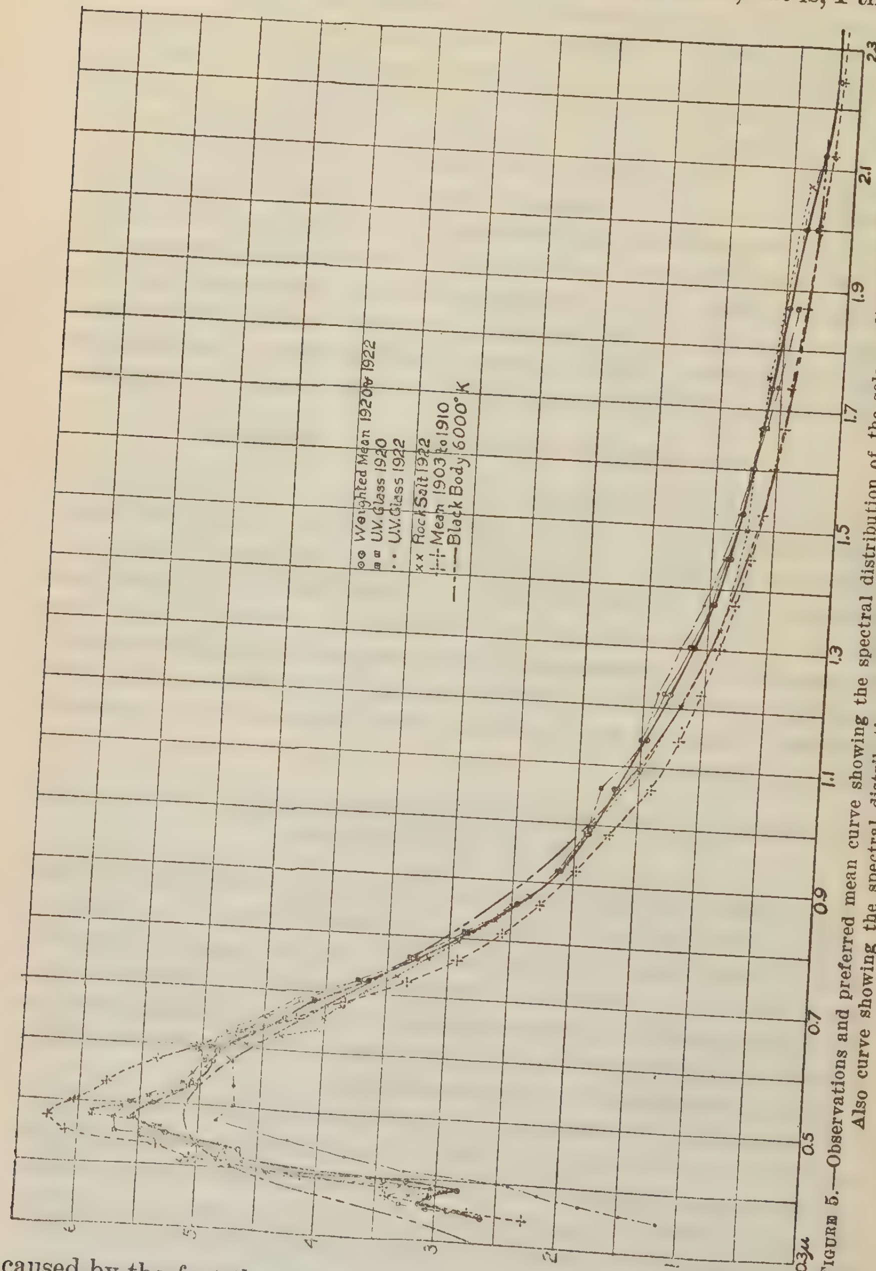

FIGURE 5.—Observations and preferred mean curve showing the spectral distribution of the solar radiation outside the atmosphere. Also curve showing the spectral distribution of the "black body" at 6,000° absolute centigrade

caused by the fact that the sun differs in several respects from a perfect radiator of uniform temperature.

THE MEAN VALUE OF THE SOLAR CONSTANT OF RADIATION

The solar-constant methods just described were used exclusively at Washington from 1902 to 1905; at Bassour, Algeria, in 1911 and 1912, and at Mount Wilson, Calif., from 1905 to 1920. Only one, or at most two, determinations per day resulted from them, and they were at the mercy of changes in atmospheric transparency during the several hours per day required. If the sky clears as the sun mounts higher, the solar-constant value is too high, and vice versa. But in the average of many days of highest apparent excellence, atmospheric changes were largely eliminated. We believe that our mean value determined during this period, 1.94 calories per square centimeter per minute, will never be greatly corrected.

THE SHORT METHOD OF SOLAR-CONSTANT DETERMINATION

In 1919 we devised a new and briefer method, less affected by atmospheric changes though dependent on the long method for indispensible data of average atmospheric transmission. If the sky is hazy and therefore bright, the atmospheric transparency is low. We found it possible to express empirically the observed atmospheric transmission coefficients at our 40 wave lengths as functions of the brightness of the sky near the sun. This brightness we measure with an instrument called the pyranometer, which we invented. We have so far perfected this short method of solar-constant measurement that five independent values of the solar constant can be observed and computed by two observers in five hours of work. We still use the fundamental long method of Langley occasionally, but only as a check to assure us that the empirical short method is still sound.

Soon after the Mount Wilson Observatory was founded by that great scientific organizer, Dr. George E. Hale, he invited Doctor Langley to conduct solar-constant work there. We carried on solar-constant measurements at Mount Wilson each summer and autumn from 1905 to 1920. By simultaneous measurements at Washington and Mount Wilson and again at Mount Wilson and Mount Whitney, we proved that the fundamental method of Langley yields equal results whether carried on at sea level, at 1,700 meters, or 4,400 meters of elevation.

THE BALLOON PYRHELIOMETER

About 1914 we constructed a form of automatic pyrheliometer which could be attached to a group of sounding balloons and used to record the total intensity of the solar beam at very much higher elevations. In July, 1914, my colleague, L. B. Aldrich, assisted by by the United States Weather Bureau, sent up one of these balloon pyrheliometers from Omaha. It was recovered uninjured in Iowa,

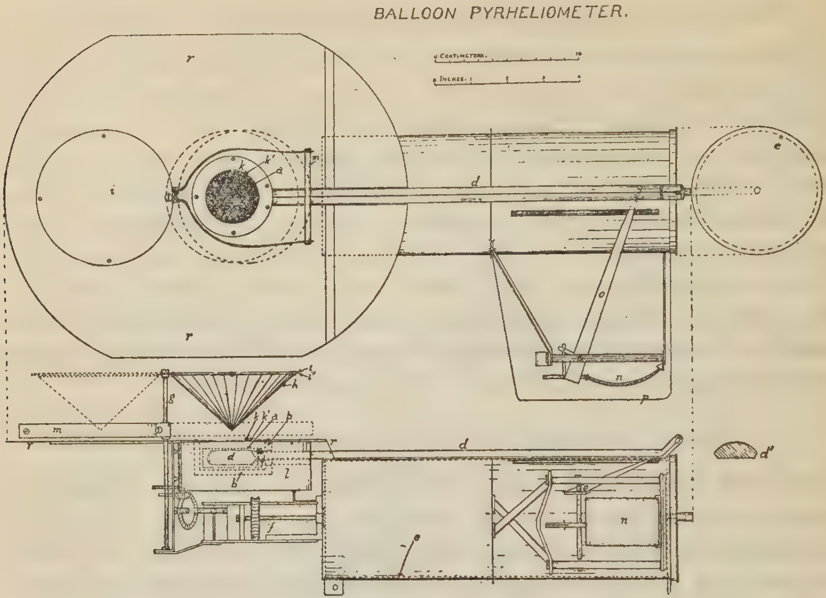

FIGURE 6.—Diagram of balloon pyrheliometer

a. Blackened metal disk; *d d*, flat-backed thermometer; *g h i*, shutter; *f*, clock rotating shutter and photographic drum; *e*, photographic recording drum; *n o*, barometric element; *r*, windbreak.

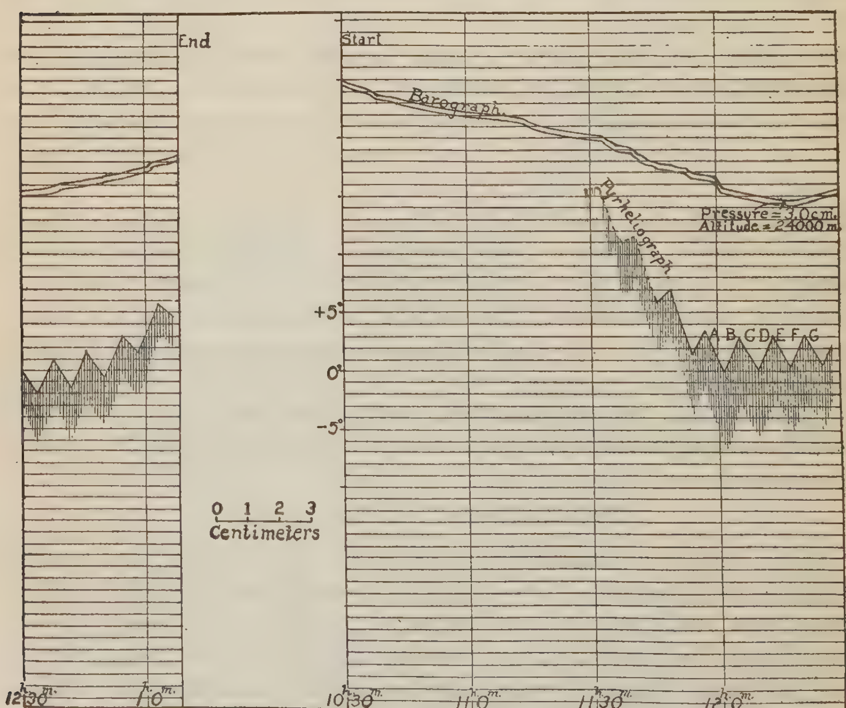

FIGURE 7.—Record of automatic recording balloon pyrheliometer, July 11, 1914

150 miles east. Thus we were able to calibrate and test it, both before and after the ascent, under the same conditions of temperature and pressure which it encountered during the flight. Correcting results to mean solar distance, this instrument recorded a solar intensity of 1.84 calories at the elevation of 22,000 meters. The barometric pressure there was 3 centimeters, so that twenty-four twenty-

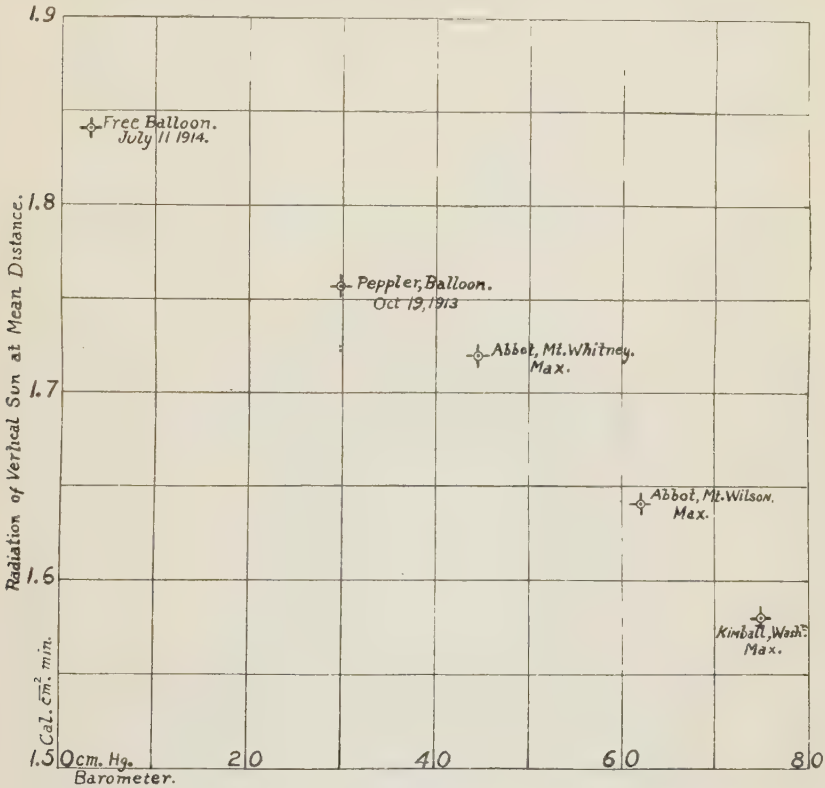

FIGURE 8.—Pyrheliometric measurements of solar radiation from sea level to 22,000 meters elevation

fifths of the atmosphere had been left behind. Allowing for the probable atmospheric absorption and scattering still remaining, the result for the solar constant is 1.87 calories, which, within the error of the determination, is certainly a good check on our adopted mean value of the solar constant, 1.94 calories.

DISTRIBUTION OF RADIATION OVER THE SOLAR DISK

Mount Wilson observations seemed to confirm our impression that the solar radiation is variable. Doctor Langley, therefore, suggested that we make daily observations of the distribution of brightness

along the solar diameter. For it seemed probable that if there are changes in the intensity of solar radiation, there must be associated changes in the distribution of brightness along the diameter of the solar disk.

We first conducted these measurements with a horizontal telescope of 140 feet focus at Washington in 1907. In 1913 we equipped a tower telescope of 60 feet focus at Mount Wilson. From 1913 to 1920 we made drifts across the sun's disk in several wave lengths of radiation on every day on which we conducted solar-constant observations. In this way we discovered indications of slight alterations in the brightness distribution along the solar diameter. These changes

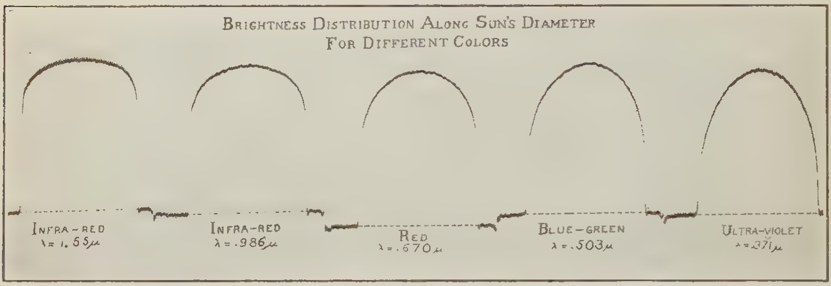

Figure 9.—Distribution of energy of radiation along diameter of solar disk

seemed to be associated with the observed variations of the solar constant. Thus in 1907 and in 1914, years of numerous sunspots and high solar radiation, there was greater contrast between the center and edge of the solar disk than in 1913, a year of minimum sun spots and low solar-constant values. The observed change of contrast was greater for shorter wave lengths. Our determination of the distribution of radiation over the sun's disk has been used in England, Europe, and Japan as a check on which to test solar theories.

SOLAR VARIATION AND THE WEATHER

In the year 1917, H. H. Clayton, then chief forecaster of Argentina, wrote that he had found relations between our observed variation of the sun and the weather of the world. He employed averages of many Mount Wilson solar-constant values in his studies, thus largely eliminating atmospheric errors. We were so keenly impressed by Clayton's results that we undertook to maintain daily solar-constant work throughout the year. At the recommendation of Dr. Walter Knoche, then in charge of the Chilean weather service, we located a new solar-constant station at Calama, in the Atacama desert of northern Chile. Later by the generous aid of John A. Roebling, we removed this station to Mount Montezuma, at 9,000 feet elevation,

about 12 miles south of Calama. Experience shows that this is probably the best station for the purpose that could be found in the whole world.

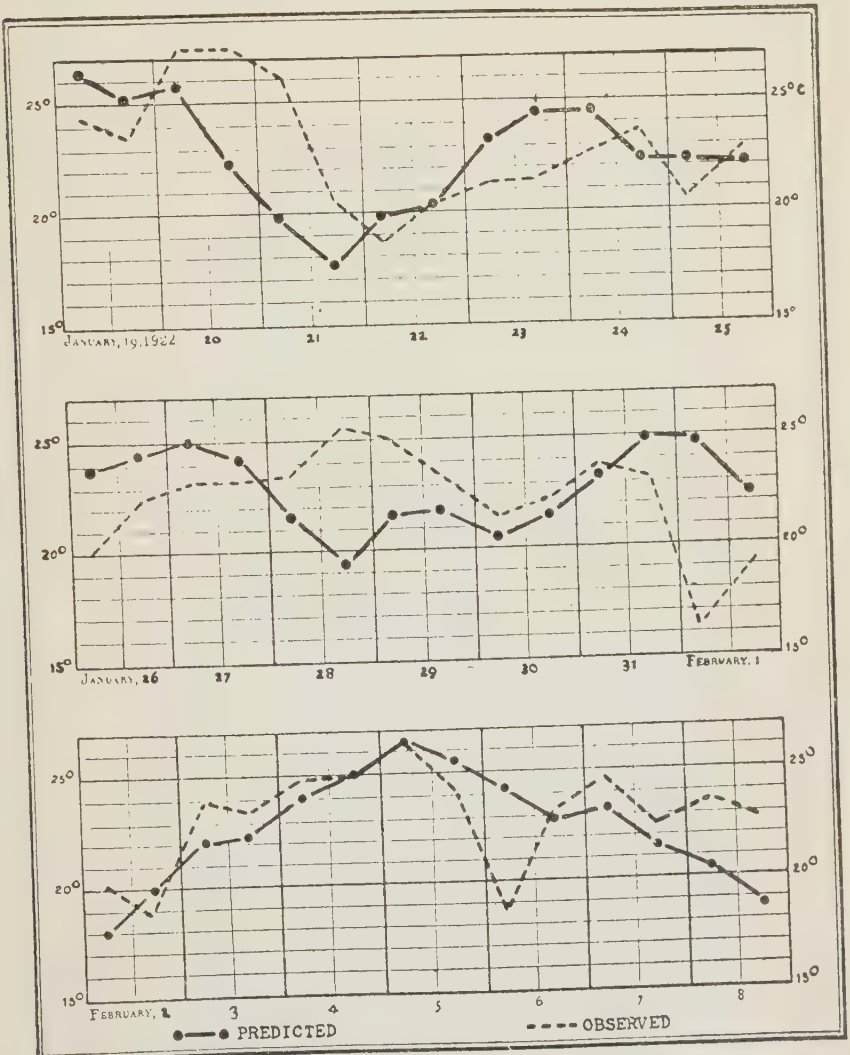

FIGURE 10.—Forecasts by H. H. Clayton a week in advance and observed verification of temperatures at Buenos Aires

FIELD STATIONS FOR SOLAR-CONSTANT WORK

In the year 1920 we removed the Mount Wilson outfit to Mount Harqua Hala, in Arizona, and in 1925 again removed it to Table Mountain, Calif., at 7,500 feet. Both removals were financed by Mr. Roebling. In 1925 the National Geographic Society appropriated

$55,000 to enable me to find, equip, and operate a solar-constant station in the best locality of the Eastern Hemisphere. After journeying to Algeria, Egypt, and Baluchistan, I chose Mount Brukkaros, in South West Africa, at 5,200 feet elevation. I am sorry to report that neither Table Mountain nor Mount Brukkaros equals Montezuma in favorable qualifications for the solar-constant work. At present, my colleague, A. F. Moore, is testing other high mountains in South West Africa and the Cape Verde Islands, hoping to find a site as good as Montezuma.

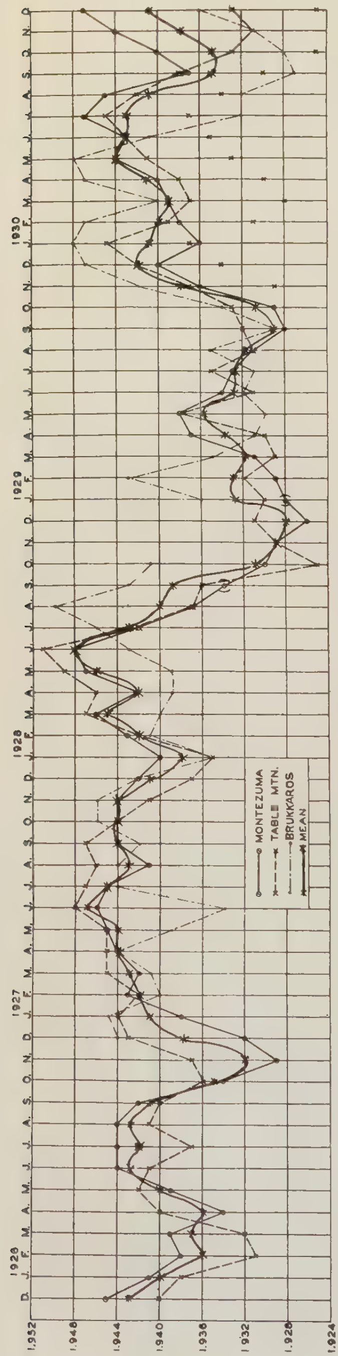

FIGURE 11.—Monthly mean solar-constant values and weighted mean curve 1926 to 1930

I have collected in Volume V of the Annals of the Astrophysical Observatory, recently issued, the results of 10 years of solar-constant work at several stations.

MONTHLY MARCH OF SOLAR VARIATION

Monthly mean values from the widely separated stations agree excellently and unite to determine the principal trends of variation of the solar radiation with adequate accuracy and certainty. As the probable error of the general mean curve is less than 0.1 per cent, we may feel much confidence in solar changes as small as one-fourth of 1 per cent when indicated by monthly mean values from three stations. The maximum range of variation of the general mean of the monthly mean values of the solar constant since 1920 is 2.8 per cent, and only 1.2 per cent since 1926. The variations of individual days may be considerably wider, so that the extreme range of solar variation since 1920 appears to be about 4 per cent.

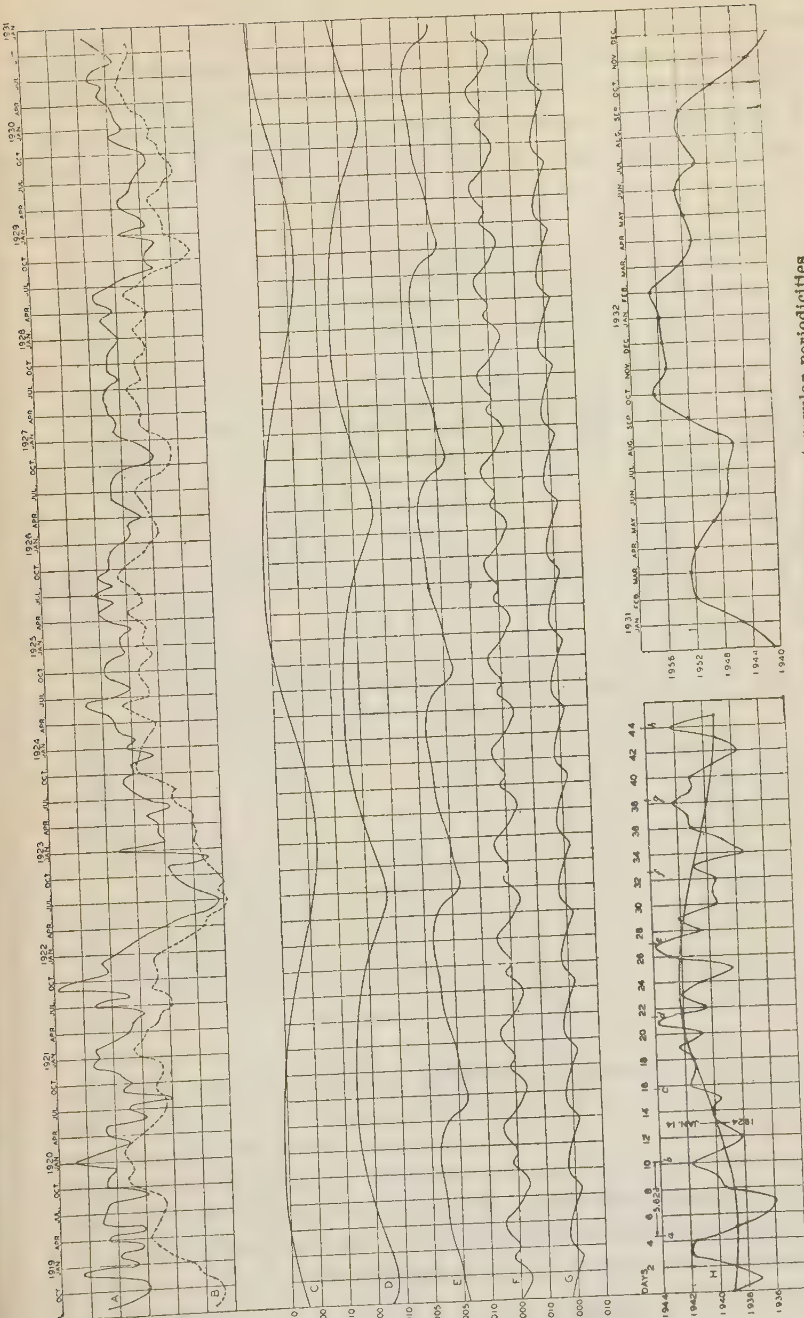

FIGURE 12.—Solar variation since 1918 analyzed into five component regular periodicities

A, monthly mean values, Montezuma. C, 68-month component; D, 45-month component; E, 25-month component; F, 11-month component; G, 8-month component; B, summation of C, D, E, F, G; H, periodicities of 45 and 5.62 days in 1924; I, predicted variation of sun for 1931 and 1932.

PERIODICITIES IN SOLAR VARIATION

Although the monthly mean variations are apparently irregular, they may be expressed with high correlation as the sum of 5 regular periodicities of 68, 45, 25, 11, and 8 months' interval, respectively. This is the more interesting because 68 and 45 months are respectively the half and third of the sun-spot period of 11¼ years.

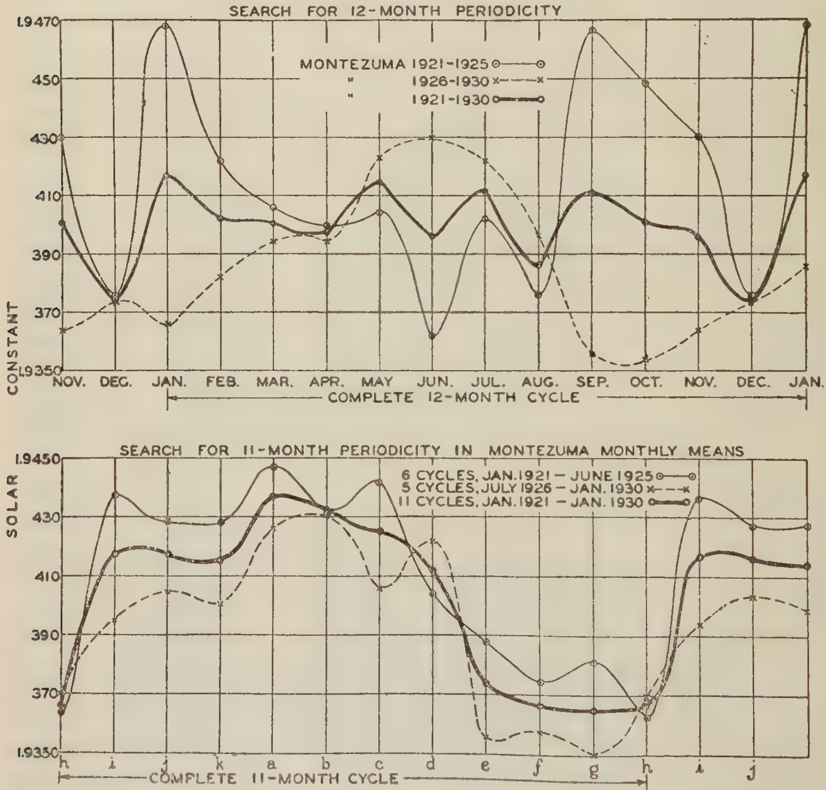

FIGURE 13.—Spurious 12-month and real 11-month period in solar-constant observations since 1920

Periodicity of approximately 25 months' interval in former centuries has been found by Dr. A. E. Douglass in the growth of trees, and by Dr. Ernst Antevs in the retreat of glaciers. Professor Marvin has claimed that our solar-constant results were affected by a 12-month periodicity, probably terrestrial. Figure 13 shows that he is in error and has mistaken the 11-month periodicity for 12 months owing to having founded his conclusion on insufficient data.

PERIODICITIES IN WEATHER ASSOCIATED WITH THOSE IN SOLAR VARIATION

I find that the five periodicities just mentioned and several others of less importance occur in the temperature of stations in the United

States. Figure 14 shows, at A and C, curves representing 5-month consecutive means of the observed departures from normal of the monthly mean temperature of Washington, and of Williston since 1918. Curves B and D show 5-month consecutive means of representations of these temperature departures as the sum of periodicities of 68, 45, 25, 11, and 8 months, which I think we may now attribute to solar variation. However, in addition to these five periodicities,

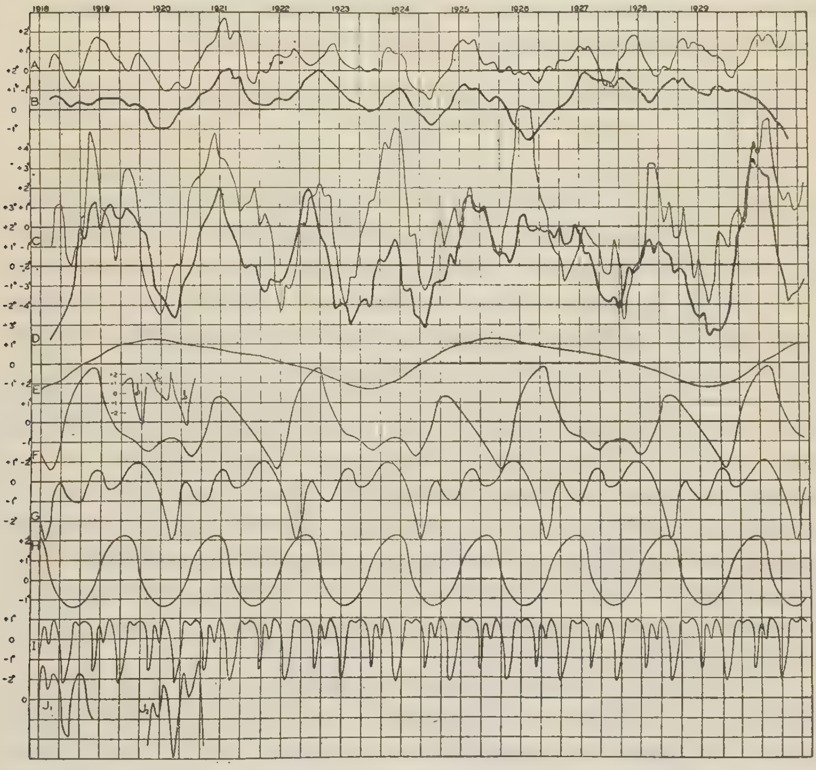

FIGURE 14.—Solar periodicities reflected in temperatures of Washington and Williston

E, F, G, H, I, periodicities of 68, 45, 25, 18, and 11 months in the temperature of Williston, N. Dak. D, their summation, and C the departures from normal temperature, both smoothed by 5-month consecutive means. B and A, similar smoothed curves for Washington temperature departures.

I found it necessary to include for both stations an important periodicity of 18 months' interval which therefore seems to be a wide-ranging terrestrial contribution. At Williston, in addition to all these, I found inconspicuous periodicities of 5, 3.6, and 3 months. It seems to me very interesting to trace the similarities and the dissimilarities of march of the curves A and C, wherein long-continued pronounced departures from the mean temperatures stand out so conspicuously.

DAILY MARCH OF SOLAR VARIATION

As regards the daily variation of the solar radiation, our results are less satisfactory. Many days are wholly lacking from the record, owing to unfavorable weather conditions, and many others are unsatisfactory. The three widely separated observing stations show a similarity, it is true, in their record of the daily march of solar variation, but are not in close enough agreement to fix it definitely. We have in mind, however, several improvements of apparatus which we hope will bring closer agreement.

WEATHER CHANGES ASSOCIATED WITH SEQUENCES OF SOLAR VARIATION

The station at Montezuma is far more satisfactory than either of the others. I show in Figure 15 the record of its daily observations since 1924. Sequences of rising and falling solar-constant values, respectively, are indicated in the figure by full and dotted curves. I prefer to segregate these by months, including in a separate group all the sequences of a given month for the seven years 1924 to 1930. I have computed the average march of departures of temperature and barometric pressure at Washington, and of temperature at Williston, associated with these instances of rising or falling solar radiation. These results for March, April, September, and October are shown in Figures 16 and 17. About 10 cases contribute to each mean curve shown. Full and dotted curves correspond, respectively, to rising and falling solar-radiation sequences. The several months differ in detail, but agree in this, that the march of weather shows opposite trends following the incidence of solar sequences of opposite directions.

It is curious and interesting to note that, though concurring with Washington in displaying this phenomenon of opposition just described, Williston temperature curves generally run in opposite sense to those of Washington. I mean that the full curve corresponding with rising solar radiation being found generally above the dotted one for Washington, we find it generally below the dotted one for Williston.

We note for both stations certain critical dates when the separation of the full and dotted curves reaches maxima. At Washington these critical dates are approximately 5, 11, and 17 days after the full development of the solar sequence. At Williston corresponding critical dates seem to occur after about 2, 7, and 13 days, respectively.

If I am right in regarding these contrasting weather phenomena as really depending on rising and falling sequences of solar radiation, I must make the assumption that the solar changes produce

primary effects in certain localized centers of influence upon the earth. Thence the effects travel southeastward in the well-known manner and reach distant localities as successive impulses at later periods depending on the distance traversed from the several centers.

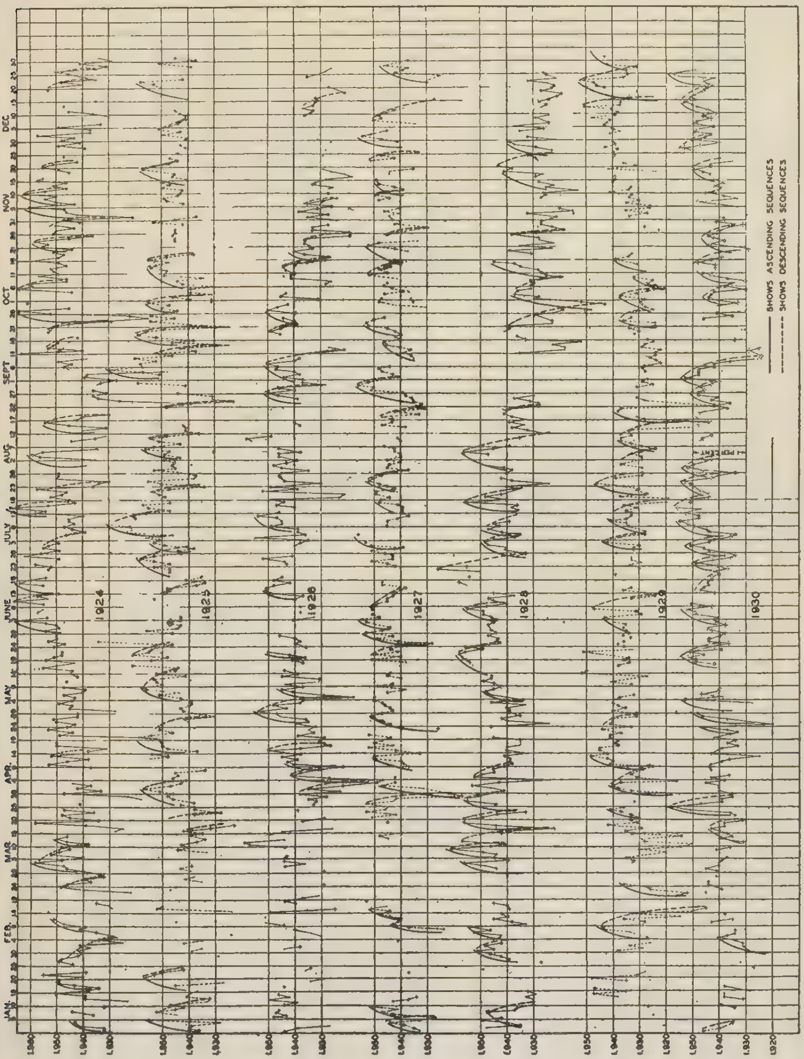

FIGURE 15.—Daily values of solar constant of radiation observed at Montezuma, Chile, 1924 to 1930. To be compared with Figures 19, 20

LAG IN WEATHER RESPONSE TO SOLAR CHANGES

The phenomena of lag in weather response to solar changes are, I am convinced, important. Mr. Clayton has produced evidence which my studies also confirm, indicating that the lag of weather effects caused by periodic solar variations is roughly proportional to the

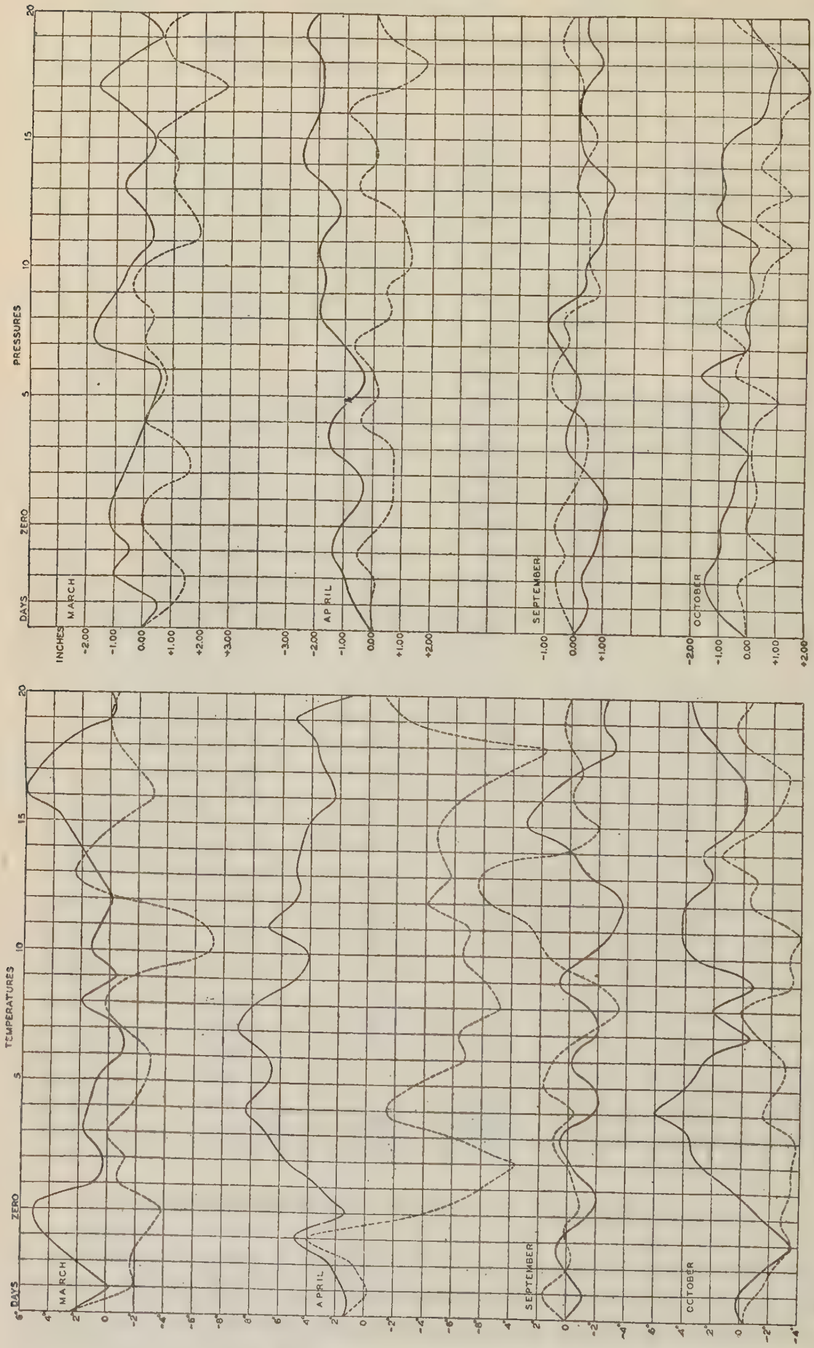

FIGURE 16.—Average march of departures of temperature and barometric pressure at Washington associated with rising and falling sequences of solar variation. Months of March, April, September, and October. Full curves correspond to rising, dotted curves to falling solar sequences. Note their oppositions and occasional wide separation. Zero day is day when solar sequence culminates

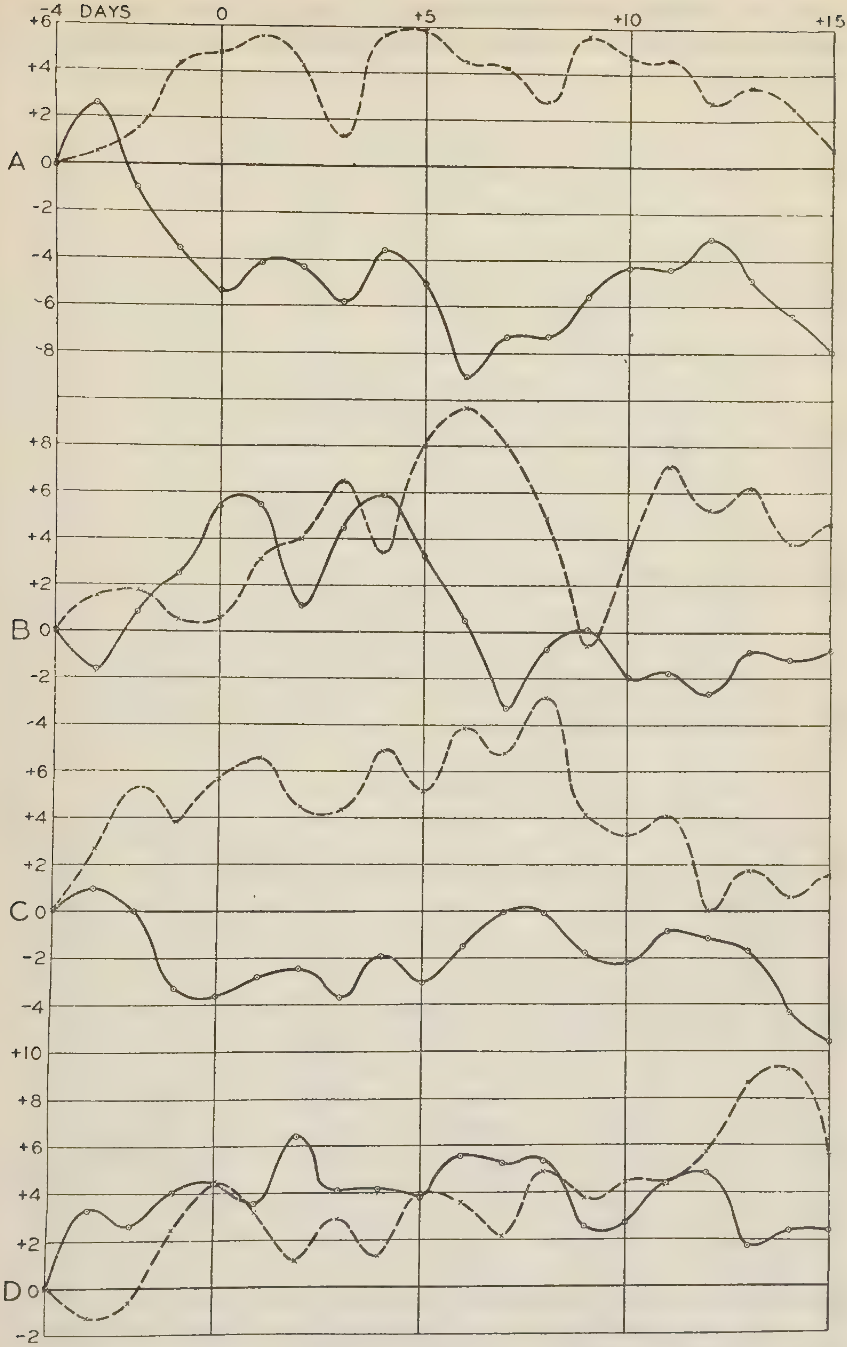

FIGURE 17.—Average march of departures of temperature at Williston, N. Dak., associated with rising and falling sequences of solar variation. Similar to curves in Figure 16. Note opposition as at Washington, but dotted and full curves usually inverted from Washington

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length of period of the solar change. Hence, if, as our results indicate, the sun is a star whose radiation varies by the combination of

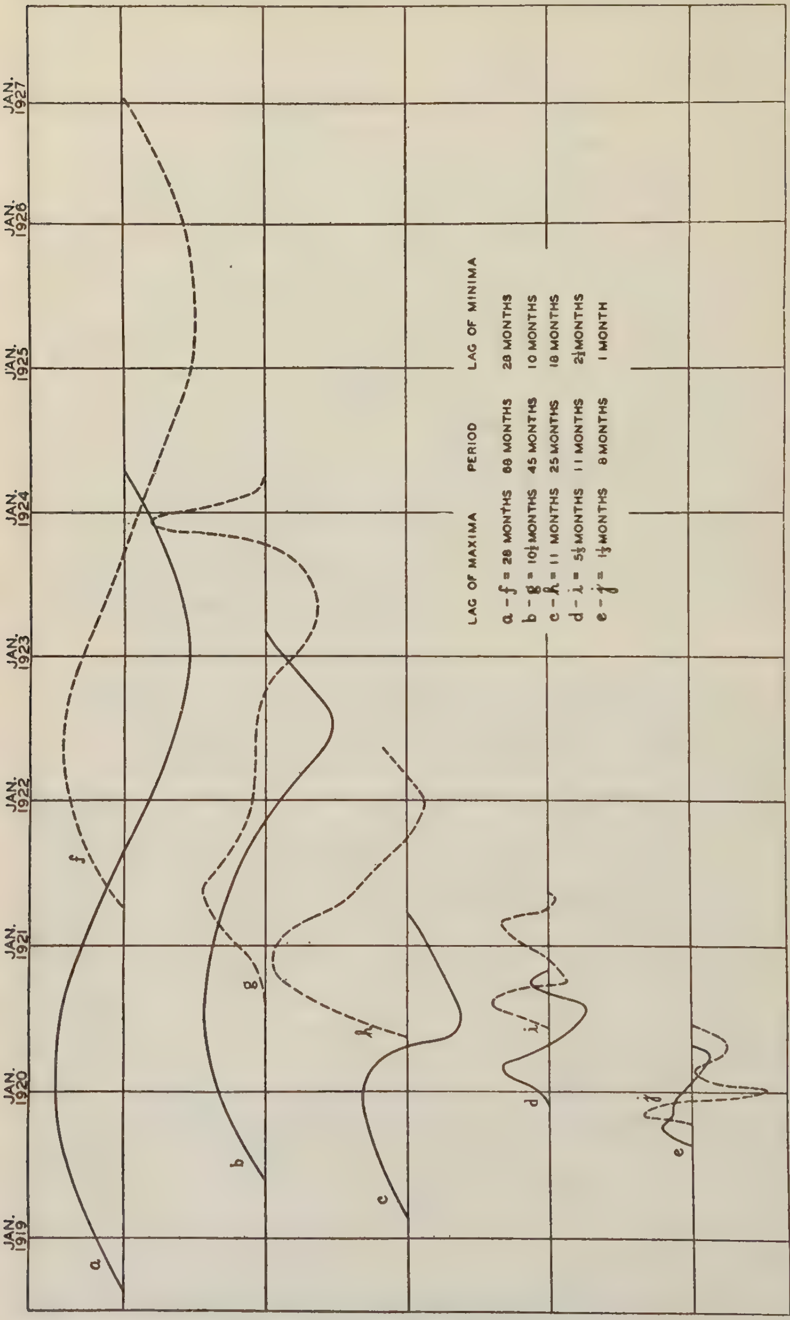


FIGURE 18.—Unequal lags of Washington periodicities of temperature departure behind the solar periodicities shown in Figure 15 a, b, c, d, e, are the solar periodicities of 68, 45, 25, 11, and 8 months; f, g, h, i, j, are the corresponding periodicities in Washington temperature departures.

several periodicities of widely differing intervals, no correspondingly marked weather change is to be expected to follow an especially

notable case of solar change, for the outstanding character of the given solar change resulted from the superposition of several periodic changes. Owing to differing lags, these periodic changes must induce weather changes at various later times, which are not superposed, and are, therefore, inconspicuous.

BY-PRODUCTS OF SOLAR-RADIATION WORK

The atmospheric transmission at about 40 wave lengths has been determined on thousands of days at many stations, including Washington, Bassour, Hump Mountain, Mount Harqua Hala, Mount Brukkaros, Mount Wilson, Table Mountain, Mount Montezuma, and Mount Whitney, ranging in elevation from sea level to 4,400 meters.

From the measured atmospheric transmission coefficients, Mr. Fowle has determined the number of molecules per cubic centimeter of gas at standard conditions. His result agrees perfectly with those obtained by other methods.

Mr. Fowle has developed a spectroscopic method of estimating the thickness of precipitable water equivalent to the water vapor contained in the atmosphere. This quantity is computed on all days when solar-constant values are determined.

Two methods of determining the quantity of atmospheric ozone from bolographic observations of the visible spectrum have been developed. Their results run parallel to those of Dr. G. M. B. Dobson.

SUMMARY

I have been dealing with the intensity of the energy of the sun's rays; its losses in the atmospheres of the sun and the earth; its inequality over the solar disk; its distribution in wave lengths in the spectrum; the development of instruments and methods to measure these phenomena; the variability of the solar radiation; periodicities in solar variation; and the dependence of weather thereon. These wide-ranging yet closely related researches have engrossed my colleagues and myself for more than a quarter of a century. They have yielded the following results.

1. Improved stability and sensitiveness of the recording spectrobolometer.
2. Accurate values of the dispersion of rock salt.
3. Mapping of about 1,500 lines and bands of solar and terrestrial absorption in the infra-red spectrum.
4. Development of the silver-disk, the water-flow, and the water-stir pyrheliometers, which have enjoyed wide acceptance.
5. Improvement of the fundamental process of solar-constant measurement.

6. Nearly 2,000 solar-constant measurements at Washington, Bassour, Mount Wilson, and Mount Whitney from 1902 to 1920, yielding a mean value of 1.94 calories per square centimeter per minute, and proving that the sun is variable.

7. Many determinations of the distribution of energy over the sun's disk for various wave lengths.

8. Many determinations of the distribution of energy in the solar spectrum, yielding estimates of the effective temperature of the sun.

9. Development of the recording balloon pryheliometer and determination therewith of the solar radiation at 25,000 meters altitude.

10. Development of the pyranometer, an instrument for measuring sky radiation.

11. A new brief method of solar-constant determination, whereby five independent values per day are obtained with minimum atmospheric influence.

12. Daily observations of the variability of the sun at several widely separated high-altitude desert stations beginning with the year 1920.

13. Determination of the march of variation of the monthly mean values of the solar constant of radiation for the past 12 years with an accuracy sufficient for all purposes.

14. Discovery that the sun's radiation varies in five continuing regular periodicities.

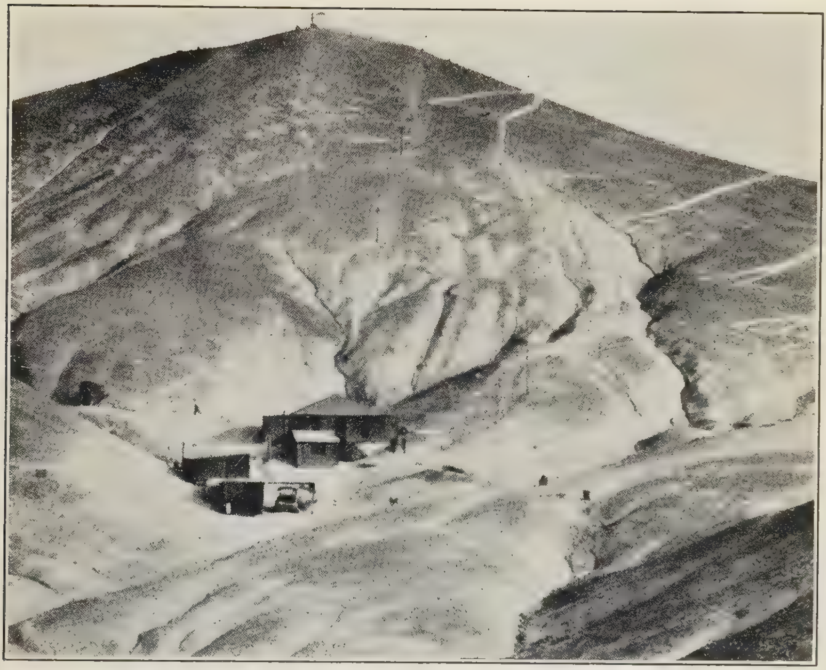
15. Indications that the weather is to a considerable degree governed by solar changes and is probably predictable therefrom.

16. By-products of the research which include determinations of atmospheric transparency, precipitable water, and ozone content.

With hope that the apparent connection between solar variation and the weather will be verified and will lead to improved methods of long-range forecasting, my colleagues and I are going on with solar-radiation studies, introducing such improvements as may help to establish a more exact record of the solar variation available for all future time.

OBSERVING WITH THE LATEST IMPROVED FORM OF THE SILVER-DISK PYRHELIOMETER

SMITHSONIAN OBSERVING STATION, ON MOUNT WILSON



1. MOUNT MONTEZUMA, CHILE, AND SMITHSONIAN OBSERVING STATION

2. THE TUNNEL OBSERVATORY AT THE SUMMIT OF MOUNT MONTEZUMA

THE COMPOSITION OF THE SUN [1]

By Henry Norris Russell

Princeton University

[With 4 plates]

Once in a long time, in the history of science, a true " royal road " is found which leads to the solution of a problem which had previously been unassailable. There is no better example than the discovery of the spectroscope. Seventy years ago, or a little more, almost nothing was known of the composition of the heavenly bodies, and there was no reasonable hope of knowing more. The high densities of the moon and the inner planets, to be sure, indicated that they must be solid bodies, probably similar in general constitution to the earth, while the much lower densities of the sun and the major planets indicated that their constitution was different, but this information did not go very far. Suddenly the hopeless quest became a reality with Kirchhoff's discovery that a rarefied luminous gas gives out light of definite wave lengths, which, analyzed by the spectroscope, produces a definite pattern of lines, fixed in position and intensity for a given source, and fully characteristic of it. Gases absorb the same kinds of light which they emit; hence the multitudes of dark lines of the solar spectrum became immediately intelligible, each carrying its own message about the sun's atmosphere. A dozen or more familiar chemical elements were then immediately identified in the outer parts of the sun and, shortly afterwards, in great numbers of the stars. This still remains the most impressive evidence regarding the fundamental unity of nature. Atoms of the very same kinds are found in our terrestrial laboratories, in the sun, the stars, and in nebulae so remote that their light takes a hundred million years to reach us. As the investigation of spectra on earth and in the heavens progressed, the correlation of the two became continually more complete. At the present time almost all the lines of any strength in the spectra of the sun and the stars can be reproduced at will in the laboratory; and the few exceptions are yielding year

[1] First Arthur Lecture, under the auspices of the Smithsonian Institution, Jan. 27, 1932.

by year. The great outstanding puzzles of the nebular and auroral spectra yielded a few years ago, and the solar corona alone remains uninterpreted.

The proof that iron (for example) is present in the sun has been for two generations a standard laboratory experiment—which ought, by the way, to be exhibited to the general public in our great science museums whenever the sun shines. The analysis of the sun would therefore appear to be a very simple matter, but, as is usual in all precise work, many complications arise.

With such strong lines as those of iron the simpler "method of coincidences" is conclusive, and many other elements—hydrogen, calcium, magnesium, sodium, aluminum—can be found at once in the same manner. Evidently, too, in a general way, an abundant element will give strong lines and a rare one weak lines, so that our analysis can be roughly quantitative as well as qualitative.

But if we wish to make it complete, we must record and measure as accurately as possible all the lines of the solar spectrum and also the emission lines of all the elements.

The solar part of this great task was first adequately attempted by Rowland. Developing the difficult technique of constructing diffraction gratings to a point which has hardly since been equalled and certainly not surpassed, he obtained photographs of the spectrum which showed the faintest lines with a distinctness which is still the envy if not the despair of other workers. His great "Table of solar spectrum wave lengths" covers the whole range from the ultraviolet to the red—as far as the best plates then in existence were sensitive—and includes more than 20,000 lines. Within this region it is substantially complete. The recent revision of Rowland's table, undertaken at Mount Wilson, has added only seven faint lines, not counting those which appear only in sun spots, and so fell outside his purview.

The principal reason for the revision (apart from the practical one that the earlier work was out of print) was that Rowland's scale of wave lengths, though a great improvement on anything which preceded it, requires correction on the average by 1 part in 28,000, and also by smaller fluctuating amounts not exceeding one two hundred thousandth of the whole, but too large to be ignored in precise work. The corrected wave lengths are good to one or two parts in a million.

Measures of comparable precision have been made in the laboratory for many, though by no means all, emission spectra. It is a dangerous thing, however, merely to compare a set of laboratory wave lengths, however precise, with the solar tables and conclude the presence of an element because a number of its lines appear. Allowance must be made, of course, for the small shift to the red in the sun, which, on the average (though not in all details) agrees with Ein-

stein's prediction. Even so, the number of solar lines is so great that a good many coincidences will occur through mere chance.

The Fraunhofer lines are relatively sparsely strewn in the red; but, even there, if we write down a fictitious wave length, quite at random, there is 1 chance in 16 that it will agree within 1 part in 500,000 with some solar line. In the green the chance is 1 in 12, in the violet and ultra-violet, 1 in 9.

In a rich spectrum, with several hundred lines, there should therefore be dozens of apparent coincidences of wave length with solar lines, many of them to one part in a million or better, by chance alone. We must evidently have some test to distinguish these spurious agreements from real ones. The obvious criterion is that, if an element is really present, the relative strength, as well as the absolute position, of its lines will be correctly reproduced in the solar spectrum. Numerical coincidences with faint lines are meaningless unless the strong lines of the element are present, and coincidences even with strong lines are suspicious if other stronger or equally strong lines fail to appear.

In this respect there are noteworthy differences between different elements. Iron, for example, is very richly represented in the solar spectrum, almost 3,300 of its lines having been identified; but it is also very completely represented, for practically every line that can be produced in arc or spark in the laboratory is to be found in the sun. There are, indeed, many faint iron lines whose positions can be accurately predicted by means of the modern theory of spectral structure. Many of these have been detected in the laboratory by long exposures, but still more appear in the sun in exactly the predicted positions and with the expected intensities.

Magnesium, though but 25 lines are recorded in the "Revised Rowland," is almost as completely represented there as iron, for its spectrum is poor in lines, and every line that could be anticipated is present.

Copper, however, which has a fairly rich spectrum, exhibits only its strongest lines in the sun, while silver reveals its presence only by its two strongest lines, and even these are faint. Gold does not appear at all, nor do mercury and bismuth. What is much more remarkable, there is no evidence of phosphorus or arsenic, or chlorine, bromine, or iodine, or of neon, argon, or their heavier homologues.

The absence of any evidence of these familiar elements in the sun's atmosphere was for a long time a perplexing problem. It was always suspected that they must really be there, but "concealed" in some fashion or other; and now this conjecture is changed to a well-founded belief.

The main key to the puzzle is that we can observe but a part of the whole spectrum of the sun or of a star. Our atmosphere, fairly transparent (in good weather!) for visible light and for the near ultra-violet, becomes suddenly opaque between 2,900 and 3,000 Angstroms—that is, at about three-quarters of the wave length of the ordinary limit of visibility in the violet. For all shorter waves it is as opaque as a stone wall. This limitation, which cuts the astrophysicist off permanently from the most interesting region of the spectrum, arises from the presence of a small percentage of ozone at the very top of the atmosphere, far too high to hope to penetrate by any known means of flight. At the other end things are not so bad. The eye ceases to be sensitive about λ8,000. Modern photographic plates run out beyond λ10,000, with hope of future gain. Energy-measuring devices, such as the bolometer used with such success by Langley and Abbot, are free from this limitation and have detected solar radiation beyond λ100,000, but they are relatively insensitive and record only a few of the strongest spectral lines. Moreover, in the infra-red the water vapor and carbon dioxide of the earth's atmosphere cut huge, wide bands out of the spectrum. We may really count ourselves fortunate that the spectral region in which it is easy to work is so little bedeviled by the influence of the earth's atmosphere, which, as my old teacher, Professor Young, used to say, translating literally from the French, "is the astronomer's black beast!"

At present our observations of the solar spectrum are impossible below λ2,900; accurate and complete from λ3,000 to λ7,300; under completion to λ10,000, with hope of considerable extension, and possible, but rough, far into the longer wave lengths.

Now, there are some elements, such as boron, which have not a single spectral line in the observable range, though there are plenty in the farther ultra-violet and presumably some (not yet discovered) in the infra-red. The same could have been said for phosphorus until certain successful photographs were taken at the Bureau of Standards a month ago (December, 1931). There is evidently no hope of identifying such elements directly in the solar spectrum.

For many other elements the strongest lines lie far out of reach in the ultra-violet. This is true for the nonmetallic elements without exception and for some metals—gold, mercury, cadmium, etc. The limitation of our observing powers puts us at a great disadvantage when it comes to such spectra. A large majority of the "absent" elements belong here.

There are several more elements of this group which have their next strongest lines deep in the red, beyond the limit to which Rowland could photograph. Modern plates reveal these lines (in all cases

faint) in the sun, and carbon, oxygen, nitrogen, and sulphur have thus been added to the list.

The second clue to the riddle is found in the fact that the same element may give different spectra under different conditions.

The importance of this was first realized by Sir Norman Lockyer more than 50 years ago. When a compound of a metal is volatilized in a Bunsen or hydrogen flame, the spectrum shows lines (usually only a few) characteristic of the metal, and often also bands (resolved with high dispersion into a multitude of close-packed lines) which vary with the compound present and are evidently due to undecomposed molecules. At the higher temperature of the electric arc, many (though not all) of the bands disappear, indicating that the compounds have been dissociated by the high temperature, while the lines—due evidently to free atoms of the metal—become stronger and more numerous. Band spectra, if present, are strongest in the light from the relatively cool outer flame of the arc, for obvious reasons. With the condensed spark between metallic poles as source, new lines make their appearance, and others which are faint in the arc are greatly intensified or "enhanced."

Lockyer suggested, more than 50 years ago, that the elements familiar to the chemist were themselves compounds which, at the very high temperature of the spark, were decomposed, and that the enhanced lines came from the products of this decomposition while the arc lines were from the unaltered element. He supported his contention by the observation that, in white stars like Sirius—which are undoubtedly hotter than the sun—only the enhanced lines of the metals appear, while in the sun both arc and enhanced lines are present. For silicon, he pointed out four groups of lines appearing in hotter and hotter stars as representing successive stages in the process of decomposition of the familiar element.

Lockyer was in advance of his times; and his bold theory, though generally doubted at first, was essentially sound. We have now every reason to believe that atoms are complex structures, composed of electrons circulating in some fashion about a nucleus. By disturbing the atoms with sufficient violence, one after another of these electrons may be removed, a process called ionization. Both neutral and ionized atoms can emit and absorb line spectra, but the two are entirely different. Spectroscopically, an ionized atom behaves like an entirely new element, and each successive ionization again leads to a wholly different spectrum. The arc lines belong to the neutral atoms, ordinary enhanced lines to atoms which have lost one of their electrons, and so on. Lockyer's four sets of silicon lines correspond to atoms possessing all their electrons, or deprived of one, two and three. The detailed theory of the process was first applied

in astrophysics by an Indian physicist, Saha, and has revolutionized our understanding of the subject.

In the solar spectrum the arc lines predominate. Enhanced lines, though numerous, are usually inferior in strength, though by far the strongest lines in our whole spectrum arise from ionized calcium (Ca^+). "Band lines" due to compounds are not conspicuous, but some were recognized by Rowland as due to compounds of carbon. Many more have since been detected, and it is probable that a great number of the faint lines which are as yet unidentified may turn out to be due to compounds whose spectra have not yet been measured with adequate precision for comparison.

A decisive test of the ionization theory is found in the spectra of sun spots. The spots, though darker and redder than the rest of the sun's surface, and obviously cooler, give off light of their own. This exhibits a very distinctive spectrum, similar in general to that of the sun, but with many differences. Some lines are much weaker, others are stronger, and some greatly strengthened. Comparison with the data of the laboratory shows that the weakened lines are practically all enhanced lines, and the strengthened lines are lines of easily ionized metals, while hundreds of band lines appear in the spots alone. At the lower temperature of the spots new compounds form which are completely decomposed over the disk, and the compounds otherwise present are increased in quantity. Ionization diminishes, so that enhanced lines fade, and arc lines strengthen. The agreement with theoretical prediction persists to the minutest detail. For an element of difficult ionization, like silicon, the enhanced lines are very much weakened, and the arc lines little, if at all, strengthened, while for one easy to ionize, such as strontium or scandium, the enhanced lines hardly change and the arc lines are enormously strengthened in the spot. This agrees perfectly with calculation, which shows that for such elements most of the atoms are ionized even above the spots, but the percentage of neutral atoms, while still small, is greatly increased there. There are three elements, lithium, rubidium, and indium, which appear only in the spot spectra. All are easy to ionize, and must be so completely ionized at the ordinary photospheric temperature that their arc lines disappear. The strongest lines of the ionized atoms are out of reach in the ultraviolet, and so we would lose them altogether from our list, were it not for the relative coolness of the spot. This actually happens for caesium, the easiest of all elements to ionize; and there are a good many other elements, such as barium and the rare earths, which reveal themselves only by their enhanced lines.

Elements of difficult ionization are also at a disadvantage in the sun, but for a different reason. Not all the lines, even of a neutral

atom, are equally easy to produce. The atom may exist in a multitude of different states, each with its own store of internal energy. We may picture the atom, if we will, by imagining the electrons revolving about the nucleus in orbits, and the different states by supposing that some of the outer orbits differ in size, shape, and inclination to one another. (This picture, though imperfect, is as good as the familiar one of "rays" of light.) Whatever picture (or mathematical formula) we adopt for the energy states, there is no doubt of their existence.

An atom which changes from a state heavily loaded with energy to one less powerfully "excited" must release its energy, and it does so by giving out light. The number of vibrations per second in this radiation—of kilocycles, to use a word now familiar to all radio listeners—is exactly proportional to the amount of energy released. No one knows why—if we did, we would be a good deal nearer to understanding the nature of things than most of us ever hope to be—but the fact is again firmly established.

Knowing this, it is possible, by a study of the spectra, to map out with very great accuracy the various energy states of a given atom and the transitions between them which cause the emission, or, when reversed, the absorption of a spectral line.

The properties of these atomic states or spectroscopic terms, as they are also called, are governed by a complicated and precise system of rules, which are now fully understood. The work of Sommerfeld, Lande, Pauli, Hund, and others has led to a theory which interprets, and, what is more, predicts, the structure of even the most complicated spectra, and enables us to specify exactly what occurs when each one of the hundreds or even thousands of lines is emitted or absorbed.

An atom, left to itself, will settle down into its normal state, with the smallest possible content of energy. From this state it may pass by absorption of light into any one of a number of others, producing certain spectral lines. Each atom is doing only one thing at a time; but among the billions of atoms in the smallest perceptible quantity of gas, all these transitions are happening at once. Those which are most likely to occur give the strongest lines.

An atom in an exited state of higher energy content absorbs a number of other lines, quite different from the first, and so on for each of the numerous exited states, till the whole complicated spectrum is built up.

Now the relative numbers of atoms in the various energy states depend on the temperature of the gas. In a cool gas practically all of them are in the normal state; but, with rising temperature, an ever-increasing though usually small proportion will be found at any moment in each of the exited states.

Sodium vapor, for example, when cool, absorbs only the familiar pair of lines in the yellow, and others in the ultra-violet, which are produced by transitions from the normal state. But at a white heat, a minute fraction (perhaps 1 in 100,000) of the atoms are in an exited state and absorb other pairs of lines in the red, orange, and green. In the electric furnace those lines are very feebly absorbed, but in the far hotter atmosphere of the sun they are stronger in proportion to the great principal pair in the yellow.

Similar phenomena occur in the more complicated spectra, such as those of titanium and iron, where there are dozens of different exited states. The behavior of the lines at different laboratory temperatures has been of great importance in working out the intricate problem of their analysis.

Once more the sun-spot spectrum confirms the theory perfectly. Lines absorbed by unexcited or slightly excited atoms are strengthened most in the spots and those of excited neutral atoms less so. For elements of easy ionization the increase in the number of neutral atoms in the spots is so great that it swamps the loss due to diminished excitation; but for elements harder to ionize, such as silicon and zinc, the reverse is the case, and the lines of high excitation potential are weakened in spots.

The same principles apply to enhanced lines. As might be expected, enhanced lines of high excitation are greatly weakened in spots, and often obliterated.

By a detailed study of the behavior of lines of all these sorts it is possible to find both the temperature and pressure in the spots. Miss Moore (of Mount Wilson and Princeton) has completed a very successful study in which she finds that the temperature of a typical spot is 1,000° lower than that of the disk, the total pressure 70 per cent higher (since the gas is more transparent and we can see deeper), but the pressure due to the free electrons 40 per cent less, owing to the diminished ionization. The agreement of theory and observation is satisfactory to the finest details.

Even at the solar temperature, 5,740°, only about 1 atom in 20,000 should be excited to the extent measured by 5 volts (that is, by the energy imparted to an electron by 5 volts' potential drop). It is easy to understand, then, why only 46 solar lines out of nearly 6,000 for which the energy relations are known are absorbed by atoms more highly excited than this.

Almost all the metals (except gold and mercury) have arc lines of low excitation in the accessible part of the spectrum, so that they are, so to speak, on an even footing in our solar lists. Some of them have similar enhanced lines accessible, (as do calcium, scandium, titanium, and the rare earths); but for many others, such

as iron and nickel, the "ultimate" lines of low excitation are beyond the observable limit in the ultra-violet, and only lines of considerable excitation are accessible. For magnesium and aluminum the only accessible enhanced lines are of very high excitation and are naturally faint, while for the accessible lines of the alkali metals the excitation is so high as to banish all hope of finding them.

Passing to the nonmetals—which are so hard to ionize that only arc lines could be expected in the sun—we find that the ultimate lines are in all cases hopelessly out of reach and the accessible lines have excitation potentials ranging from 6 volts upward. Our spectroscopic tests for these elements are therefore at best perhaps a hundred-thousandth part as sensitive as they would be if we could observe the far ultra-violet, and the wonder is not that we fail to find some of them but that we do find any. Carbon, sulphur, and nitrogen, though they show only faint lines, must be as abundant as the commoner metals. Oxygen, whose lines are stronger, must be still more so. But hydrogen is really amazing. Despite the very high excitation potential of 10.15 volts, its lines are among the strongest in the solar spectrum. It may be that a large allowance should be made for the peculiar character of its lines, which are exceptionally susceptible to widening by the electric fields of neighboring ions, and hence to apparent strengthening. But, even so, there appears to be no escape from the conclusion that hydrogen is far more abundant in the sun's atmosphere than any other element—much more so, indeed, than all the others together.

For the elements which do not appear in the solar spectrum, the excitation potentials of the best available lines are in most cases hopelessly high. There may be some chance of finding phosphorus when its spectrum has been investigated in the infra-red, but this is all.

An unexpected aid in our search has, however, recently appeared. More and more band spectra are being identified in the sun; that is, more species of molecules detected in the atmosphere. Most of these are compounds of hydrogen, oxygen, or carbon, but boron oxide (BO) was detected a few years ago in sun spots by Nicholson and Perrakis, and silicon fluoride (SiF) more recently by Richardson, both in the spots and on the disk—adding two more elements to the list of those positively identified in the sun. The other compounds so far identified (some in spots only) are the hydrides CH, NH, OH, MgH, AlH, SiH, CaH, the oxides AlO, TiO, ZrO, and the carbon compounds CN and C_2. It is possible but not certain that molecules of hydrogen (H_2) may exist in sun spots.

The chemist will gaze with open eyes at this list. All but the last are mere fragments of molecules, already partly decomposed and too active chemically to be isolated in ordinary temperatures. But it

is not surprising that such partial decomposition occurs at the sun's temperature. It is probable that a few other more familiar molecules (notably CO and N_2) exist in the sun's atmosphere, but these molecules, in their normal state, absorb only in the far ultra-violet and can not therefore be detected.

The hydrides are known to be rather easy to dissociate, and their presence in the sun is additional evidence of the great abundance of hydrogen. All the other compounds which have been detected contain at least one constituent which is known to be very abundant in the sun's atmosphere in the free state.

Last, but not least, comes helium, which shows strong emission lines in the spectrum of the sun's outer atmosphere—the chromosphere—but no dark lines on the disk, except occasionally in disturbed regions near spots. The emission lines were recognized at solar eclipses 60 years ago, and for 20 years could not be matched in the laboratory, so that the name "helium" was coined to describe the unknown solar element. How it was detected in radioactive minerals, found to be a light inert gas—as had been suspected from the height to which it rises in the chromosphere—and finally discovered in natural gas in such abundance that it is used in airships, is one of the romances of science which can barely be mentioned here. It is still the outstanding puzzle of solar physics. Its visible lines demand very high excitation—20 volts or more—so that it is not surprising that they do not show in absorption, but very remarkable that they appear so strongly in emission at the sun's limb. In fact, one line of ionized helium ($\lambda 4686$) with the enormous excitation potential of 48 volts appears faintly in the chromosphere; why, no one yet knows.

All told, 61 of the 90 known chemical elements have so far been identified, positively or with some margin of doubt, in the solar spectrum. Of the remaining 29, 13 have lines so unfavorably placed that they could not well be expected to appear, while for 12 more the spectra have not been accurately enough measured to permit of a decisive test. This leaves four elements—holmium, rhenium, bismuth, and radium—for which the strongest lines are in accessible regions of the spectrum, and do not appear in the sun. These metals must be present only in minute proportions, if at all, in the solar atmosphere. Holmium is one of the rarest of the rare earths. Rhenium appears to be exceedingly rare on earth, and radium, on account of its short life, must be rare anywhere in the universe, so that we could not expect to find it or any of the other strongly radioactive elements in perceptible amounts.

So much for the qualitative analysis of the sun or, at least, of its outer layers. What can we do to make our analysis quantitative?

Here new difficulties beset us. We may ask, what is the total amount of iron vapor in the sun's atmosphere per square mile (or square centimeter) of its surface? But the sun has no definite surface. At the top, of course, its atmosphere thins out gradually into space, like the earth's. But at the bottom it is not limited by a solid surface, or even by a cloud layer, but becomes gradually more and more hazy, so that we can not see down very far. This increasing opacity is due to the presence of free electrons and ions in the gas, as was first shown by my colleague Stewart, of Princeton, and later worked out in more detail by Milne, of Oxford. Milne's calculations indicate that the change from extremely low density to practical opacity takes place in a layer only about 20 miles thick, which explains the sharpness of the sun's limb, even as seen with the largest telescopes.

By far the greatest part of the absorption which produces the Fraunhofer lines takes place in this thin reversing layer. In the upper part of it the atoms are few, but get in their full effect, while the more numerous atoms lower down are "blanketed" to an increasing degree by the general opacity of the layers above them. Milne has shown that the net effect of this partly obscured absorption is very nearly the same as we would get if the atmosphere were perfectly clear—except for the specific line absorption—down to a certain depth and quite opaque below this, and that we may introduce this imaginary surface at a level in the actual atmosphere such that the gas above it blocks one-third of the escaping light in the regions between the spectral lines.

The amount of material above this fictitious surface is surprisingly small. This was first pointed out by Lockyer, who showed by direct comparison that a Bunsen flame an inch or so thick, charged with a very small proportion of sodium vapor by a bit of salt held on a platinum wire, absorbed the ultimate lines of the metal more strongly than the whole thickness of the sun's atmosphere. This very important conclusion was almost forgotten for 40 years, and revived only in our own day, with so powerful a support from atomic physics as to be irresistible.

Stewart and Unsöld have shown theoretically that the width of a dark spectral line, produced in a rarefied gas, should be proportional to the square root of the number of atoms per unit area in the absorbing layer (no matter what its thickness) which are active in producing this particular line. The strongest solar lines are wide enough to make measures of their contours practicable—though not easy—and the corresponding numbers of atoms per unit area "above the photosphere" can thus be deduced. For the strongest lines of all (the H and K lines of $Ca+$, taken together) this comes out 2×10^{19} atoms per square centimeter, which equals the number of molecules in a layer of ordinary air one-third of an inch thick.

For the sodium lines the calculated number is only one nine-hundredth as great, thus supporting Lockyer's old conclusion.

For the thousands of fainter lines similar measures would be very laborious and of doubtful value, since a number of other influences, solar and instrumental, produce a small widening of the lines. A recent admirable investigation of the green magnesium lines by Prof. H. H. Plaskett, of Harvard (and soon of Oxford), shows that the prediction of dark solar lines is a much more complicated affair than is supposed in the simpler theory already mentioned, and that exact calculation of the number of atoms active in producing them is very difficult. Some other line of attack is to be desired, and one is opened by the modern theory of spectra.

Most spectroscopic terms are multiple, with from two to seven components. Combinations between two such terms give rise not to single lines but to groups of from 2 to 19 lines, called multiplets. Some lines in such a group are much stronger than others, and their relative intensities—that is, the relative number of atoms engaged in their production—can be calculated from the quantum theory, independently of the temperature, pressure, and other conditions.

We may now have (for example) 2 lines in the same multiplet, of which the stronger has the intensity 4 on Rowland's arbitrary scale, and the weaker intensity 1, while the formulae indicate that 40 times as many atoms are at work on the first as on the other. Another pair of lines with the same Rowland intensities may give the theoretical ratio 25, another 50, and so on—for Rowland's estimates are rather rough. But great numbers of lines are available, and the average of all gives a good determination of the relative number of atoms which produce lines of various intensities on Rowland's scale. In this way Doctor Adams, Miss Moore, and the writer have calibrated Rowland's scale. The same difference in his intensities corresponds to a greater difference in the numbers of active atoms for lines in the violet than in the red; but this can be allowed for. With the aid of the strong lines which have been individually measured, the actual number of atoms which are at work in producing a solar line of given intensity may be found.

For a line of Rowland's intensity 0—just well visible with ordinary high dispersion—there are about 10^{13} atoms at work per square centimeter, or enough to make a layer of gas, under standard conditions, a little over a ten-millionth of an inch thick. The faintest lines of all require about a twentieth as much.

We may now find how many atoms of each element are engaged in producing each one of its observable lines. To find the total number of atoms of this element, in the solar atmosphere, we must allow for those which give lines in the infra-red and ultra-violet, which we can not observe. This can be done if we can get at all the

important lines which are absorbed by the atom in at least one of its energy states (whether normal or excited), for the numbers in other states can then be calculated by thermodynamic theory, know-

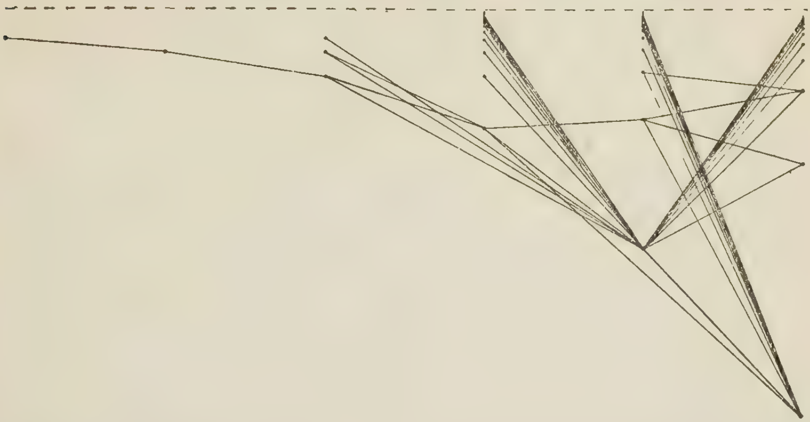


FIGURE 1.—Diagram showing the energy levels of the sodium atom. The dots represent the individual atomic states. They are set at heights corresponding to the energy content of the atom. The lines represent those transitions which can actually occur and produce spectral lines. An atom in the lowest energy state absorbs only a certain series of spectral lines, one in the next highest energy state, two other series of lines. (See text.)

FIGURE 2.—Similar diagram for the spectrum of titanium. The number of energy states is very large, and the transitions between them give a very complicated spectrum

ing the sun's temperature. In this way the numbers of neutral atoms have been found for many elements. Most ionized atoms have all their best lines in the far ultra-violet and are not amenable to our treatment, but there are several whose numbers can be found. Now

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the proportion of the atoms of any element which are ionized depends not only on the temperature, but on the pressure (and also, of course, on the ease of ionization of the element).

We know the proportion for half a dozen elements whose strongest arc and spark lines are both accessible, and so we can find the pressure—or, at least, that part of it due to the free electrons. At the level of the "photosphere" (as defined above), this comes out one twenty-thousandth of the "standard atmosphere." We can now calculate that an element with an ionization potential of 8.5 volts would be half ionized and half neutral. Most of the metals are more easily ionized than this. Only one atom of sodium in a thousand is neutral, and less than one in a hundred for calcium. One-fifth of the iron atoms, and one-third those of silicon, are neutral; but 85 per cent are neutral for zinc, 99.6 per cent for carbon, and all but one in 30,000 in the case of hydrogen. Making the appropriate allowances, we find the total amounts of the various elements in the sun's atmosphere. For the metals, the results should be fairly reliable. They indicate that six elements,—sodium, magnesium, silicon,[2] potassium, calcium, and iron—furnish 95 per cent (by weight) of all the metallic vapors, and six more nine-tenths of the remainder, as is shown in Table 1.

TABLE 1.—*Metals in the sun's atmosphere*

[Tons per square mile]

Magnesium	350	Cobalt	6
Iron	250	Chromium	6
Silicon	150	Titanium	2
Sodium	100	Vanadium	1½
Potassium	50	Copper	1½
Calcium	50	Zinc	1
Aluminum	15	All others	0.2
Nickel	15		
Manganese	10	Total	1,008

This is very much like the order of relative abundance that is found on earth. The results of Clarke and Washington (based on hundreds of careful analyses of typical rocks) show a greater abundance of silicon, aluminum, and titanium. But these results represent the composition of the outer 10 miles of the earth's crust, which is composed mainly of granitic rocks, richer in these three elements than are the far thicker layers of dense rocks deeper down.

Again, nickel and cobalt are much less abundant in terrestrial rocks than in the sun. But in meteorites (which are probably more representative of the general composition of the solar system than is the siliceous slag, which forms the outer layers of the earth) they occur in nearly the same proportions as in the sun.

[2] Silicon behaves spectroscopically like a metal and is therefore included here.

Among the rare elements there is a general parallelism between solar and terrestrial abundance. Some elements, of which the most noteworthy is scandium, appear to be much more abundant in the sun than here; but small quantities of these, widely disseminated among the rocks, may well have escaped the search of the ordinary chemist, even though skilled. The actual amounts even of the rare elements, in the sun's atmosphere, are very great. For example, platinum is represented only by three faint lines in the solar spectrum; but to produce these there must be something like 500 million tons of the precious metal above the photosphere. This amounts, however, to less than 8 ounces per square mile of surface, or one-eightieth of an ounce per acre. An equal amount, rained down in thin dust on the earth's surface, would not be worth the labor of sweeping up.

The amounts of the nonmetallic elements are much harder to determine in the sun, for the only available lines come from atoms in highly excited states. For every atom in such a state there are a very great number in the normal state—sometimes millions—and these huge factors are hard to determine accurately. As has already been said, carbon, sulphur, and nitrogen must be as abundant as the commoner metals, oxygen more so, and hydrogen far more abundant than all the rest.

In the hotter stars, where lines of ionized oxygen, nitrogen, etc., and of neutral helium, are conspicuous, a better comparison can be made. Miss Payne, of Harvard, working a few years ago by methods developed by Milne, derived values for the relative abundance of a number of elements and reached the very important conclusion that the stars are remarkably similar in composition. The great differences in their spectra arise, not from differences in the abundance of the elements, but in their ionization and excitation at different temperatures. Her results, and those of the writer's later work, are in remarkably good agreement.

Combining them in a final summary, we may conclude that at least 90 per cent of all the atoms in the sun's atmosphere—and perhaps 95 per cent or more—are atoms of hydrogen. Of the remainder, helium and oxygen contribute some two-thirds, and all the metals, together with carbon, sulphur, etc., the rest.

These are the proportions of the various constituents by volume in the gas. By weight, the metals, whose atoms are much heavier, make up a quarter of the whole (or less, with the higher estimates of the abundance of hydrogen).

Whether the sun's interior is of the same composition is a harder question. The great ascending cyclonic whirls which produce sun spots must come from a considerable depth, but from only a very small fraction of the way to the center. Whether the deeper layers are sufficiently stirred by currents to undo the very small tendency

for the heavy atoms to settle gradually to the center is not certain, but it appears to be fairly probable.

The remarkable differences in the abundance of the elements are as yet almost unexplained; this is a problem for the next generation of physicists, and a fascinating one. It is natural to imagine that the many different elements have been produced in some way or other, out of a more primitive material—perhaps out of hydrogen, which is the simplest, and in many ways seems fit to be the raw material for the rest. Abundant elements would then be those that have been formed in large amounts, while the rare ones have either been less likely to form, or more likely to change over into something else.

One general relation, first pointed out by Harkins, of Chicago, is conspicuous. Elements of odd atomic number are much less abundant than those of the adjacent even numbers. There is hardly an exception among the 56 elements included in the study of the sun's atmosphere, and on the average the even elements are eight times as abundant as the odd ones.

This must have something to do with the stability of the atomic nuclei, but no one yet knows how.

Another very striking case has been accounted for. Lithium and beryllium, the lightest elements next to hydrogen and helium, occur in surprisingly small amounts in the sun, less than a hundred thousandth part as much as either these lighter elements or heavier ones like oxygen or iron. Atkinson, of Rutgers, has accounted for this by a theory of the building up of atoms out of hydrogen in the intensely heated interior of the sun or of a star. In such a region the lighter atoms are stripped of all their electrons and reduced to bare nuclei, which collide violently with one another. Once in a very long time (as atomic events go) a hydrogen nucleus, or proton, will hit some other nucleus so hard that it penetrates it and stays there, forming a new nucleus, of greater atomic weight. The wave mechanics indicate that the probability of such penetration is much greater when the charge on the nucleus is small, and hence the lithium or beryllium atoms, if originally present in large numbers inside a star, would get built up into heavier ones, till in the final "steady state" very few were left. This process of atom building liberates a great amount of energy, sufficient to keep the sun shining for thousands of millions of years.

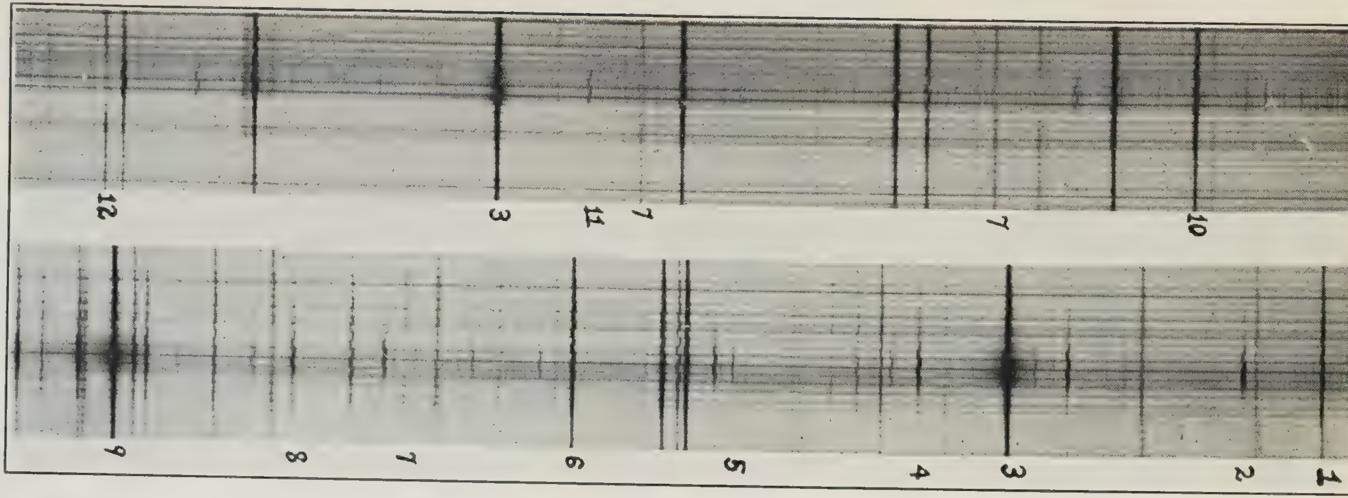
This theory, though beautiful and most promising, is still provisional. It is probable, however, that with increased knowledge regarding the composition of the stars and the sun, as well as of their masses, densities, and other characteristics, a great deal more can be found out about the past history and the evolution both of stars and of atoms than anyone knows now.

THE SUN'S SURFACE PHOTOGRAPHED WITH THE SPECTROHELIOGRAPH IN HYDROGEN LIGHT (MOUNT WILSON OBSERVATORY)

Note the sun-spot regions strongly marked by bright hydrogen flocculi.

A GREAT SUN SPOT. ENLARGED FROM A DIRECT PHOTOGRAPH (MOUNT WILSON OBSERVATORY)

It will be noticed that the whole solar surface shows an indistinctly mottled appearance. There are no clouds on the sun. This mottling is due merely to temperature differences which cause differences of brightness of the hot bases which send us light.



SUN-SPOT SPECTRUM. PHOTOGRAPHED AT MOUNT WILSON

A small portion of the spectrum in the red under very high dispersion. A number of lines which are strengthened or weakened are marked. Barium is completely ionized both over the disk and spots. Its lines are strengthened in the spot spectrum because the gas, being less ionized, is more transparent and we can see down deeper.

Red Section of Sun Spot Spectrum

No.	El.	λ	Behavior in spot	No.	El.	λ	Behavior in spot
1	Ni	λ6108	Strengthened.	7	Fe+		Weakened.
2	V		Do.	8	Na		Strengthened.
3	Ca		Do.	9	Ca	λ6162	Do.
4	Ti		Do.	10	Fe	λ6408	Do.
5	Zr		Do.	11	Y		Do.
6	Ba+		Do.	12	Fe+	λ6456	Weakened.

EVIDENCE OF IRON IN THE SUN (MOUNT WILSON OBSERVATORY)

The bright line spectra are produced in the laboratory. The dark line spectra above and below are solar. Note that every bright line has its dark solar counterpart. Many other dark solar lines appear also. These are produced by the existence in the sun of other vapors than iron.

SUN SPOTS AND RADIO RECEPTION[1]

By Harlan T. Stetson

Director, Perkins Observatory, Ohio Wesleyan University

[With 2 plates]

Of all astronomical bodies the sun is by far of the greatest immediate concern to human beings. Literally in him we live and move and have our being. Every square yard of the earth's surface exposed to direct sunshine receives energy at the rate of more than one-and-a-half horsepower; the whole earth receives from the sun heat at such a rate that if converted into doing work it would represent the equivalent of 230,000,000,000,000 horsepower. With the exception of a few experimental solar engines once set to work for irrigation purposes in arid regions, man has practically made no attempt to convert, directly, solar rays into mechanical effort. Perhaps when oil is running low and coal is $100 a ton we may learn to tap profitably this abundant source.

When we reflect, further, that, after all, the whole earth can intercept less than one-billionth of the sun's total output, we realize our complete inability to conceive of this stupendous and seemingly inexhaustible supply. To determine conditions at the surface of the sun and to measure its temperature, which is about 12,000° F., is a far simpler task than to divine the source of its enormous energy or to conjecture just what is going on in the interior.

However, the sun is a typical star, and, thanks to the researches of Eddington at Cambridge University, we are no longer as ignorant as we once were concerning the interior of the stars, and our best guess as to the source of their radiant energy leads us into the very structure of the matter of which stars are made. We may picture the interior of the sun as a veritable hurly-burly of atoms and electrons, flying hither and thither at terrific velocities which rapidly increase as the sun's center is approached, where the temperature is of the order of 80,000,000°. From this hot interior of the sun must ultimately arise the source of solar radiation, which not only

[1] Revision of paper originally presented at a meeting of the Franklin Institute held Thursday, Feb. 13, 1930. Reprinted by permission, with change of title and other revision, from the Journal of the Franklin Institute, October, 1930.

manifests itself in familiar light and heat but in a wide variety of electromagnetic disturbances, whose far-reaching effects we are just beginning to appreciate.

Studies during the last few years indicate that there are cosmic causes at work which may profoundly influence the electrical state of the earth's atmosphere which radio waves traverse. Probably the sun is the one astronomical body most responsible for changes in our terrestrial affairs. Every radio listener knows that daytime reception is vastly poorer than night-time reception in the broadcasting zone. Here is the most obvious exhibition of the effect of the sun's rays upon radio. On the other hand, both day and night reception vary greatly from time to time for what has often seemed no good reason at all. It is from relatively very recent researches that we have come to believe much of the cause for this varying degree of reception is to be found in the sun's atmosphere itself.

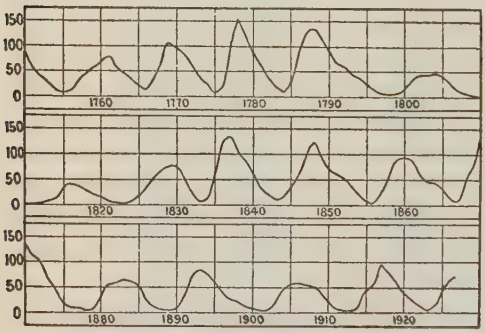


FIGURE 1.—The sun-spot curve, according to Wolf's sun-spot numbers. (From data by Wolfer)

When we examine the sun's surface through the telescope, we find that it presents a strange mottled, or granulated appearance. In this mottled surface there develop now and then dark patches, often growing into huge black areas surrounded by a somewhat shaded region called the penumbra. These dark areas are the sun spots. Whatever may be ultimately accepted as the best explanation of the spots, one can not go far wrong in picturing a sun spot as a terrific storm in the sun's atmosphere, a cyclonic whirlwind for which the most violent tropical hurricane would be a microscopic illustration.

One of the most extraordinary features of sun spots is the periodicity with which they appear on the solar surface. For nearly a century and a half sufficiently accurate records of the appearance of sun spots have been made, so that if we plot the degree of spottedness of the solar surface year by year, we discover a periodic rise and fall in the stormy condition of the sun's surface spanning approximately 11 years. We are now not far from what we call a sun-spot maximum. About eight years ago sun spots were very scarce, and when they occasionally appeared were very small and insignificant affairs.

Curiously enough, at the beginning of a sun-spot cycle the spots appear on the sun's surface at relatively high latitudes and as the

cycle progresses they increase in size and number and break out at successively lower latitudes on the solar sphere, a given cycle of spots finally disappearing just a few degrees from the solar equator.

The true character of sun spots as magnetic whirls in the solar atmosphere was first established by Hale, of the Mount Wilson Observatory, in 1908.[2] By means of the newly invented spectro-heliograph, Hale was able to photograph different layers in the solar atmosphere and establish the existence of vortices similar to the whirlwinds which are characteristic of cyclonic storms in the earth's atmosphere. Furthermore by analyzing with polarizing apparatus the character of the rays of light radiating from the sun spots, Hale was able to demonstrate that the light emitted from the center of these gigantic whirls betrayed unmistakably that they were

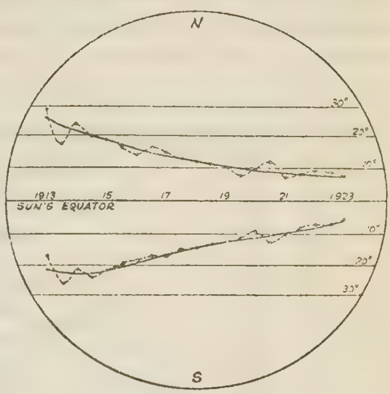


FIGURE 2.—As the 11-year sun-spot cycle waxes the latitude of the spots decreases

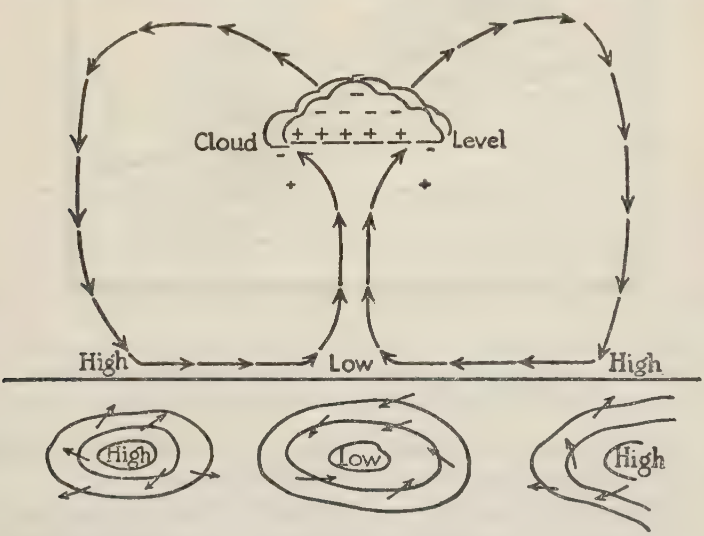


FIGURE 3.—Formation of a thunderstorm is analogous to the formation of a sun spot. Note the vertical whirls about "High" and "Low" pressure areas

electromagnetic poles and that the doubling of the lines in the spectrum over sun spots was due to the magnetic effect announced by Zeeman in 1896.

[2] Astrophys. Journ., vol. 28, p. 315, July to December, 1908.

With the reappearance of the last sun-spot cycle it was firmly established that the polarity of these spots completely reverses from one cycle to the next.[3] It has been recently suggested by a Norwegian scientist, Bjerknes[4] that the sun spots are the visible ends of a tubular vortex which may extend east and west for great distances below the sun's surface. A reversal in the direction of whirl in

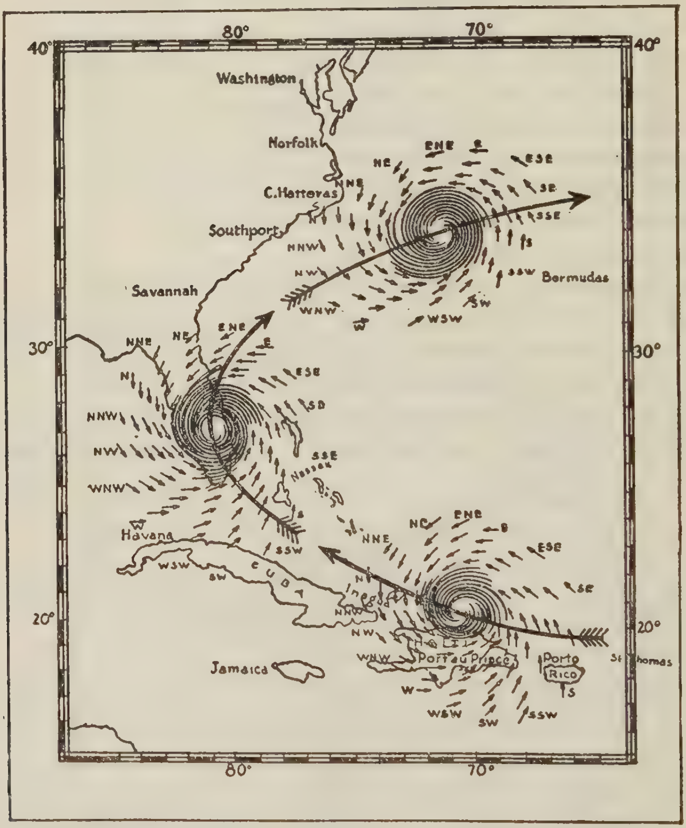


FIGURE 4.—Tropical storms on the earth frequent latitudes corresponding to the latitudes of many major spots on the sun

this supposed vortex would account for a reversal of the magnetic polarity of the sun spots with the change of cycle.

No completely satisfactory explanation of the ultimate origin of these whirls has yet been made. There is one peculiarity, however, in the sun's behavior which doubtless has an important bearing on this point. While the sun rotates on its axis from west to east in common with the axial rotation of other bodies in the solar system, its period of rotation is not the same for different parts of the solar surface.

[3] Idem, vol. 49, p. 153, January to June, 1919.
[4] Idem, vol. 64, p. 93, July to December, 1926.

Near the Equator the sun rotates once on its axis in a period of almost 24½ days, whereas in latitude 35° the motion of the spots across the surface indicates that almost 26½ days are consumed in a single rotation. Spectroscopic observations make it possible to determine the rate of rotation in regions of higher latitudes than those in which the spots appear. In latitude 60° the rotation period is nearly 31 days. The continual slipping of the atmospheric layers of lower latitude past those of higher latitude must result in the formation of eddy currents favorable to the formation of cyclonic whirls, thus producing sun spots.

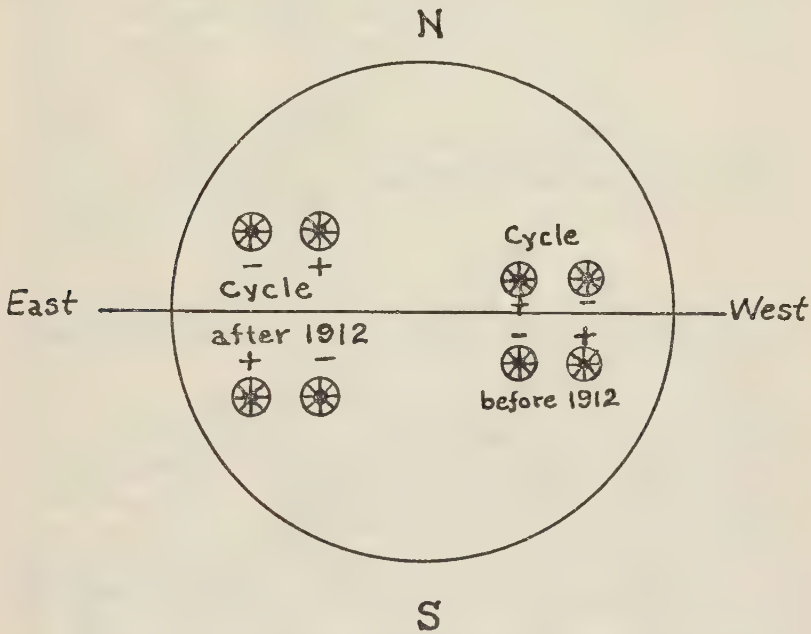


FIGURE 5.—Showing reversal in the magnetic polarity of the spots with change in cycle

The mention of sun spots invariably raises the question of a possible connection between the spots on the sun and terrestrial phenomena. Some statisticians with an insatiable appetite for correlations have attempted to connect with sun spots almost every cycle in world affairs from fluctuations in the New York stock market to the fecundity of rabbits in northern Canada. In the popular mind almost every world catastrophe has sooner or later been attributed to sun spots, from a Florida hurricane to the great World War, both of which, by the way, did not culminate around a sun-spot maximum.

But, seriously, there are to the scientist certain well recognized phenomena on the earth which pass through cycles whose correlation with the sun-spot cycle is unmistakable.

For more than a century and a half records of the numbers of sun spots have been kept and afford data for a study of their periodicity over a range of about fifteen 11-year cycles. For more than a century records of the variation in the earth's magnetism have been made and preserved. The remarkable correlation of sun spots with magnetic changes on the earth is at once apparent when we make a graph of the number of sun spots and compare this with a similar graph for changes of the compass needle (fig. 6). Simultaneously with the so-called magnetic storms, which are wont to sweep

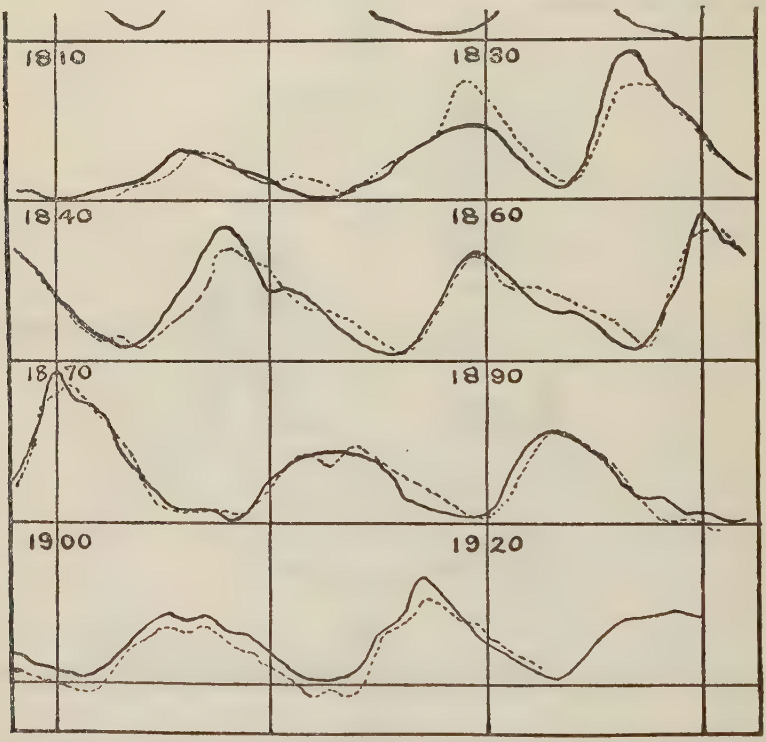


FIGURE 6.—Graph showing correlation of sun-spot numbers to magnetic effects on the earth

the earth upon the appearance of great sun-spot activity, we witness frequent and brilliant displays of the aurora borealis.

The auroral light is due to an electronic discharge in the upper and highly rarified atmosphere of the earth and is most probably activated by charged particles of electricity emanating from the sun, whose activity varies with the sun-spot cycle. It seems probable that the magnetic vertical whirl of sun spots acts as a directing field in guiding electrons escaping from the sun. When a conspicuous spot appears near the center of the solar disk, and is therefore approximately in line with the earth and the sun's center, there is

a particularly good chance of the ejected electrons striking the earth's atmosphere and causing an ionization, or electrification, of the upper atmosphere, giving rise to an auroral display. At the same time the induced earth currents will distort the earth's magnetic field, causing the small variations in the compass needle so characteristic of a "magnetic storm."

While for many generations scientists have recognized the recurrent cycle in solar activity and the magnetic changes in the earth, never before the present period of sun-spot activity has it been possible to study so thoroughly the changing degree of electrification in the earth's atmosphere with the coming and going of the spots across the solar disk. All this has come about by the development of the radio.

The same electric disturbances which alter the earth's magnetic field and produce the displays of the aurorae, or northern lights, so change the electrical state of our atmosphere that the radio waves are also affected to a very marked degree by the coming and going of the gigantic solar cyclones.

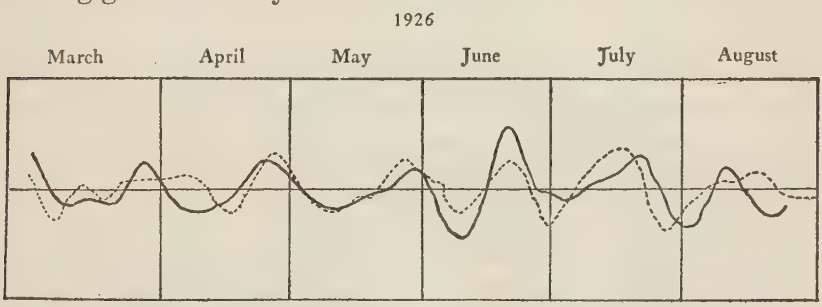


FIGURE 7.—Curve showing correlation of sun spots with radio reception; full curve, relative intensity of radio reception on transatlantic, South American, and continental reception

In the adjoining figure is a graph showing the number of sun spots during the 12 months of the year 1926 and another graph showing the average condition of radio reception over the North Atlantic and the South Atlantic and across the Continent. The sun-spot graph is made from the so-called Wolfer numbers and is plotted with an inverted scale, i. e., the larger the numbers the shorter the ordinate of the curve. These Wolfer numbers are based upon the number of spots visible on the sun's surface at a given time and to some extent upon their area, but do not take into account the position of the spot on the sun's disk. The general run of these graphs indicates that radio reception is distinctly impaired by an increase in the sun-spot numbers.

Quantitative measurements of radio reception since 1926 seem to have established beyond much doubt that long-distance night reception in the broadcast zone is in general poor when sun spots are

numerous and good when the spots are few (fig. 8). The quantitative measurement of radio reception in the broadcast zone was begun by Dr. G. W. Pickard in his private laboratory in Newton Center, Mass., in February, 1926. Great credit is due to Doctor Pickard[5] for his contribution in this field and his stimulus to other workers. In February, 1928, a duplicate set of apparatus was installed at the astronomical laboratory at Harvard University and the measurements carried on there under the direction of the author. Simultaneous records made for a short time at both receiving stations gave the necessary reduction factor for rendering those two

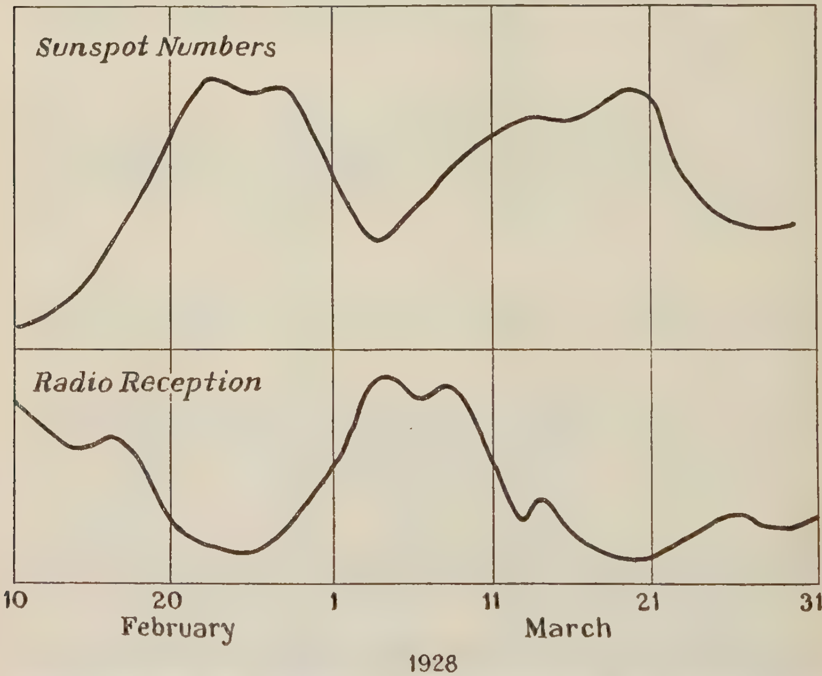


Figure 8.—Showing that the intensity of radio signals varies with numbers of sun spots. Based on data received in Cambridge from WBBM Chicago

series of observations comparable. The investigations at the Newton Center laboratory were then shifted from the broadcast zone to the region of 18 kilocycles.

Figure 8 shows in the upper graph the inverted curve of sun-spot numbers, and in the lower graph the intensity of the carrier wave of WBBM broadcasting station as received in the vicinity of Boston for 1926–1929, and is based upon the results of measurements made by Dr. G. W. Pickard and the author, working in Newton Center and in Cambridge, Mass.[6] The radio intensities are recorded in terms of microvolts in the antenna of the receiving circuit.

[5] Proc. Inst. Radio Eng., vol. 15, nos. 2 and 9, 1927.

[6] Publ. Amer. Astron. Soc., vol. 6, p. 244, 1931; Pop. Astron., vol. 37, p. 388, 1929.

In making plans for research at the new Perkins Observatory at Delaware, Ohio, it was decided to use the opportunity to further the present investigation by establishing an additional station in the middle West at one-third the distance from WBBM over which we were operating in Massachusetts. Another observer, Mr. Brown, of Pasadena, Calif., is gathering similar data from a Pacific coast station. The continuance of the Boston data is assured through the cooperation of G. W. Kenrick at the Tufts College Laboratory, Medford, Mass.

Now, every night, Sundays and holidays included, stations in Massachusetts, in Ohio, and in California tune in on a prescribed wave length to study the effect of the day's solar radiation upon the electrical state of the earth's atmosphere.

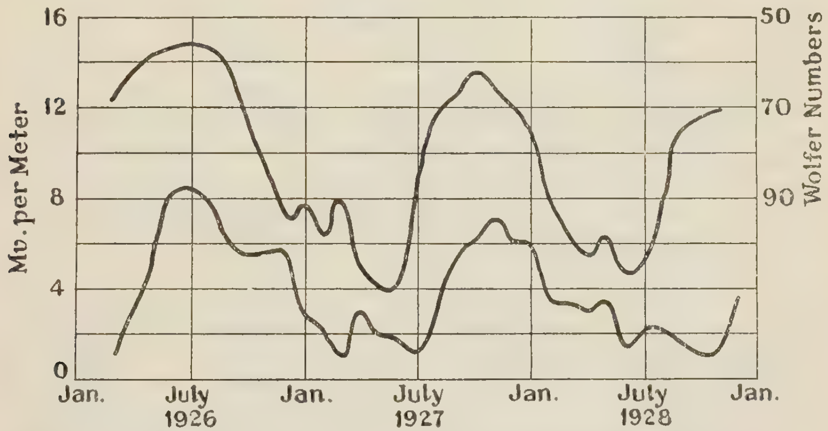


FIGURE 9.—Upper curve is inverse of running mean of sun-spot numbers. Lower curve running mean of radio signal strength received at Boston from WBBM Chicago

In addition to the measurement of radio reception, the sun is photographed at the Perkins Observatory every clear day in cooperation with the Yerkes, Mount Wilson, Harvard, and Naval Observatories, and a careful study made of the size, numbers, and location of the sun spots. It is believed from a preliminary study that the distance of the spots from the center of the disk, or the sun-earth line, is an important factor in the study of correlation of sun spots with radio reception and other electromagnetic phenomena on the earth.[7]

The radio apparatus in use at the Perkins Observatory is a superheterodyne receiver especially constructed for the purpose, and feeding into a self-recording galvanometer which registers the strength of the carrier wave received from the broadcasting station of WBBM, Chicago, and WJZ, New Jersey. The apparatus is so designed that

[7] Pickard, Proc. Inst. Radio Eng., vol. 15, no. 12, December, 1927.

the modulations of the carrier wave do not affect the record appreciably and the results obtained are independent of the nature of the program broadcasted. Realizing the importance of the investigation, the broadcasting station scrupulously maintains a constant energy output in its antenna current, and each night before the observers begin work the receiving set is carefully calibrated by means of a small local oscillator in the laboratory placed in close proximity to the receiving set. The output of the local oscillator necessary to maintain full deflection of the recorder in the receiving circuit is then read from the micro-ammeter in the circuit. The constant of the apparatus for the evening is thus determined. In this way local

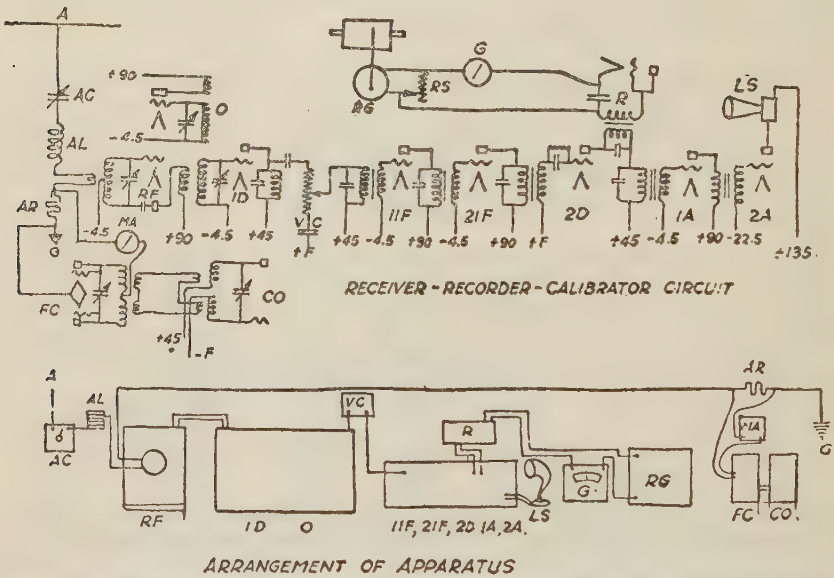


FIGURE 10.—Diagram of radio receiving circuit for recording intensities in the carrier wave

sources of error, both at the broadcasting and receiving ends, are eliminated and the resulting measure of the variable reception from night to night may be attributed to the changing electrical conditions of the atmosphere through which the broadcasted wave travels en route to the receiving station.

Opinions differ as to just what happens when a broadcasted wave travels over the earth. Some believe that an ether wave is propagated which is reflected back to earth from an ionized layer of the earth's atmosphere, known as the Kennelly-Heaviside layer, which lies some 70 kilometers above the earth's surface. Others maintain that the electric wave is refracted rather than reflected from such a layer. Whatever the mechanism, the wave appears to be turned back by this ionized layer of the earth's atmosphere. Any change in the

intensity or degree of this ionization or electrification of the earth's upper atmosphere would have the effect of bending the ray more abruptly or less abruptly toward the earth and thereupon at once be noticed in the intensity of radio reception. The more rapid changes of this sort are doubtless responsible for the phenomena of fading, with which every radio fan is thoroughly familiar. According to our theory the sun constantly bombards the earth's atmosphere with electrons or bundles of energy of high frequency, which in turn tear apart the positive and negative charges of the atmospheric molecules, in other words, ionize it to a very considerable extent, thus producing the Kennelly-Heaviside layer. If the sun is more active on occasion, as when large spots appear on its surface, the degree of ionization increases, producing substantially the effect of lowering the Kennelly-

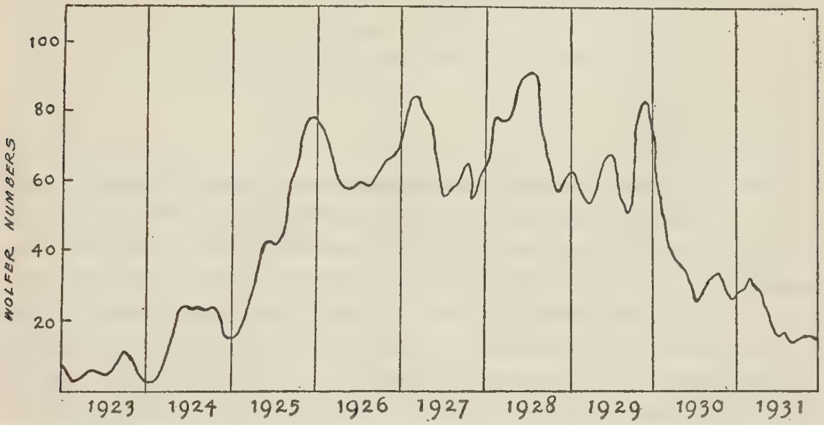


FIGURE 11.—Graph of Wolfer sun-spot numbers (3-month running means) showing 15-month fluctuation in rising solar activity since last minimum in 1923

Heaviside layer and upsetting the radio reception. When the sun is again less active, the atmosphere tends to return to its normal state of ionization and the radio broadcasting reception tends to improve as the ionized layer lifts.

For certain wave lengths it is possible that the effect of a rising and falling ionized layer may actually be the reverse of that noted in the broadcasting zone, giving impaired reception during less solar activity. Curiously enough, this is just what has been observed by Doctor Pickard at the Newton Center laboratory when working on long waves of 18-kilocycle frequency.

Further study of the data shows a definite 14 or 15 month period in solar activity to be exhibited both in the matter of sun spots and in radio reception.

Another important result of the study of the reception curve is to show how completely unfounded is the popular impression that radio reception is universally poor in summer and good in winter.

Generally speaking, reception should be better in the winter months on account of the shortened days and decreased daylight. On the other hand, the sun spots and radio curves of 1926–1928 show that the increased solar activity gave much poorer reception in the winter months of both 1926 and 1927 than during the summer months of the same years. Conditions again improved in 1928, but reception again became poor in the fall and winter of 1929. It may be mentioned that the high degree of static due to thunderstorms in the summer months results in the fact that the average radio listener will decrease the sensitivity of his set in summer to lessen these disturbances with the necessary accompaniment of low audible intensity of distant stations. Hence the general impression of a low intensity accompanying warm weather temperature.

The radio reception registered in 1929 has tended to follow the same 15-month cycle in the sun-spot numbers with a marked depreciation during the recent fall maximum, when, under normal conditions, radio reception should have been improving with the decreasing hours of sunshine.

Some progress has been made by Doctor Pickard and others in the correlation of the temperature changes with radio reception, and while concomitant variation markedly exists it is doubtful if the relation is one of cause and effect. It seems far more plausible that changes in the solar activity are more directly responsible for variations in the signal strengths received than that such should be dependent upon any absolute values of atmospheric temperature.

The subsequent rise in sun-spot numbers corroborated to a remarkable degree a prediction ventured at the New York meeting of the American Association for the Advancement of Science, in 1928, that the period of maximum for the present 11-year cycle had not been passed. Forcasting on the basis of the 15-month cycle, which had worked so effectively during the preceding years, the year 1930 was expected to show a general decrease in sun-spot numbers as the year waxed, with a corresponding increase in radio signal strength in the broadcast zone. By the very end of 1930 and the beginning of 1931 the general rise of a secondary sun-spot maximum became evident. By 1931, however, it was believed that we should be so far from the maximum of the 11-year period that the secondary maximum period should have no such marked effect upon radio reception and allied electromagnetic phenomena as did the sun-spot maxima of 1928–29. Such has been proven to be the case by the subsequent observations. The curve of radio intensities received since observations have been made at the Perkins Observatory is shown in Figure 12, the ordinates increasing from the top toward the bottom of the figure. The trend of this inverted curve of radio reception with the curve of decreasing sun-spot numbers is self-evident. The

general lifting of the ionization level in the earth's atmosphere may be expected to continue with fluctuations through the next three years, but in 1934 solar activity should be as quiescent as at the last minimum in 1923.

With the assistance of Marvin Cobb, nearly 3,000 hours of recording data have accumulated to date (January, 1932), which is making rapidly available a store of material for more extensive investigations.

Through an analysis of existing data it has become possible to determine the percentage change of intensity of signal strengths as a function of the distance of the receiving station from the subsolar

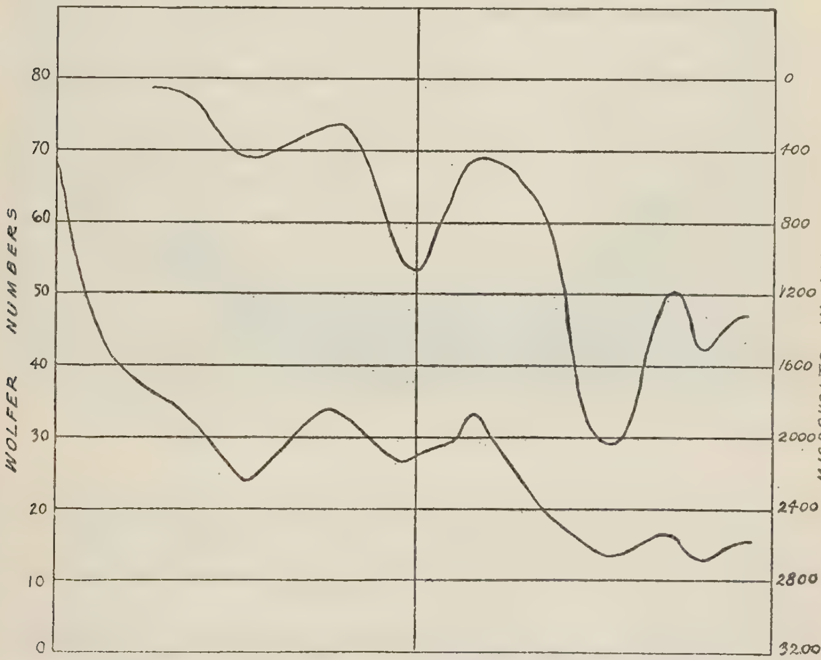


FIGURE 12.—Correlation of radio reception and sun spots from observations recorded at Perkins Observatory 1930 and 1931

point. This makes it possible to apply important corrections for twilight observations which enter into part of the records during the summer months. These corrections have already served to minimize some of the less obvious departures in radio reception from the expected values which follow generally the inverse trend of sun-spot numbers.

An examination of three years' radio data has revealed the apparent dependence of the intensity of reception upon the position of the moon in the sky at the hour of observation, radio reception in general showing 100 per cent increase in strength at those times when the moon is well below the horizon.

Further studies of the lunar effect are being pursued at the Perkins Observatory which give promise of evaluating further corrections to the radio curve for more direct comparison with the curve of sun-spot numbers.

Perhaps the most remarkable result of our correlation study has been the discovery that radio apparatus has become an effective tool in the study of solar radiation. Furthermore, since meteorological changes are correlatable with changes in radio reception, it is but fair to specify that a new method has been evolved which may ultimately lead to important correlation between sun spots and the

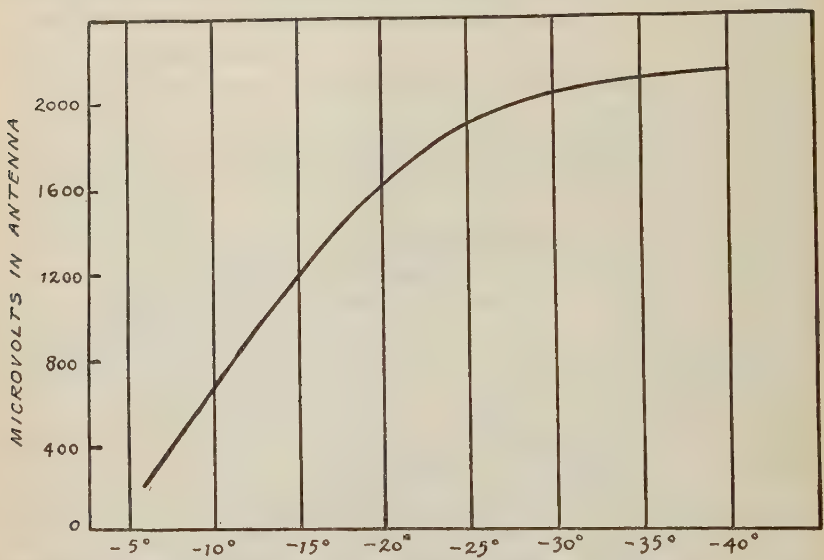


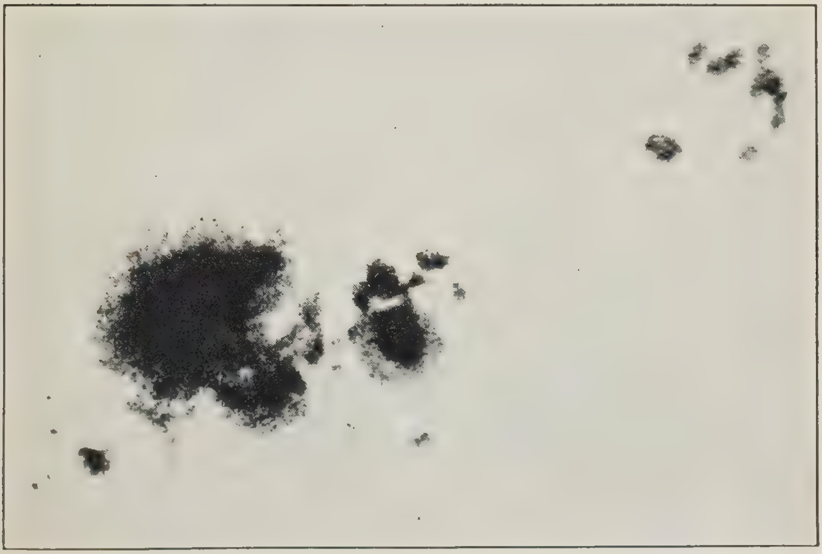
FIGURE 13.—Curve showing changing intensity of WBBM at Delaware, Ohio, as function of solar altitude

weather. To this end researches will be continued in these closely related lines at the Perkins Observatory.

Grateful acknowledgement is due the American Academy of Arts and Sciences for grants from the Rumford Fund to aid in the purchase of apparatus for this new field of research in radiation, and to the American Association for the Advancement of Science for assistance in the making of the observations and reductions.

In conclusion, it may be said that investigations in radio transmission, together with researches in the change in the earth's magnetism and electricity and the ultra-violet radiation of the sun, may yet prove to furnish the most definite data as to changes in the sun itself.

1. THE SUN PHOTOGRAPHED AT PERKINS OBSERVATORY



2. AN ENLARGED VIEW OF A TYPICAL GROUP OF SUN SPOTS

Automatic Recording Radio Apparatus at Perkins Observatory

AN EVOLVING UNIVERSE[1]

By Sir James Jeans

Former Secretary of the Royal Society of London; Research Associate, Carnegie Institution of Washington

[With 5 plates]

When we look upwards in a clear night, we see a sky spangled with stars; we can see between two and three thousand with our un-

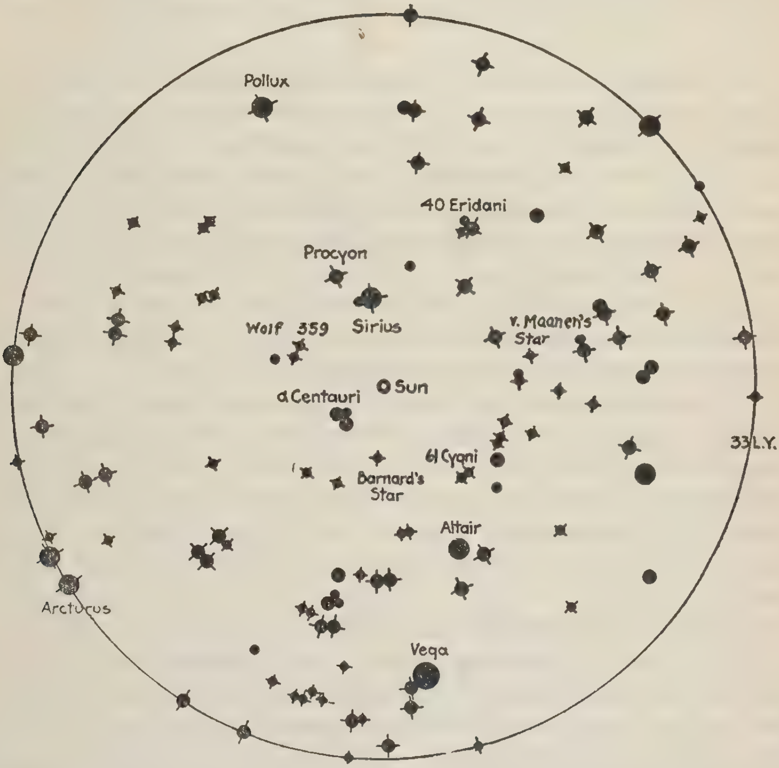


Figure 1.—Diagram showing all stars whose distances are less than 33 light-years. The size of the dots indicates their relative luminosity

aided eyes. Some appear very bright and some very faint; astronomical investigation shows that this results in large part from their being at very different distances. The stars which look brightest are

[1] Lecture delivered before Carnegie Institution of Washington, May 18, 1931. Printed by permission of Carnegie Institution. All photographs of nebulae used herein were taken at the Mount Wilson Observatory except as otherwise noted.

so near that their light takes only a few years to reach us, but the faintest we can see are, for the most part, at distances of about 3,000 light-years; that is to say, they are so remote that their light has to travel through space for about 3,000 years before it reaches us—we see them by light which left them before the beginning of the Christion era.

Besides this collection of individual stars, we also see a band of faint pearly light encircling the whole sky; we call it the Milky Way. This also consists of stars, but of stars which are too distant to be seen as individuals by our unaided eyes, although numerous enough to appear as a continuous cloud. Thus, the sky which our unaided eyes disclose to us, consists of two distinct parts—a foreground, consisting of separate stars, and a background, formed by a continuous cloud of distant stars. No middle distance can be seen by the unaided eye.

Yet telescopic observation at once discloses that a middle distance exists. Like the foreground and the background, it consists of stars—in this case, of stars which are too distant to be seen individually without telescopic assistance, and yet are not sufficiently numerous to form a continuous cloud; for it is only in the direction of the Milky Way that the distant stars lie close enough together to affect our eyes. The telescope shows that this middle distance of stars connects the foreground of individual stars with the background which we can only see as a band of light, and it becomes possible to study the system of stars as a continuous whole.

Such studies have shown that the system of stars is shaped like a disk or a coin or a cartwheel. Perhaps the last of these three comparisons is the best, because it has now been found that the system of stars is in a state of rotation. Early investigators, Sir William Herschel in particular, imagined that the sun must be somewhere near the hub of this wheel; we now know that it is at a great distance away.

It is so far away that even the brightest stars near the hub are too faint to be seen by the unaided eye. The farthest stars our unaided eyes can see are only about 3,000 light-years away from us, while the hub of this great wheel of stars is probably something like 40,000 light-years away. We still do not know the diameter of the wheel with any approach to accuracy, but it is probably something like 200,000 light-years. Still less do we know the total number of stars which constitute the wheel. It is almost certainly greater than a hundred thousand million and may quite well be two, three, four, or even five times this number.

Thus, we shall get the best picture which modern science can give us of our system of stars if we think of it as shaped like a cartwheel,

with the sun perhaps a third or a halfway along one of the spokes, and rotating like a cart wheel. The Milky Way is formed of all the stars which are at great distances from the sun, including of course the great number which are near the rim of the wheel.

The wheel is held together by the gravitational attractions of the different stars of which it is composed. As a consequence, the outermost stars move with the slowest speeds and take longest to perform a complete revolution—just as in the solar system the outermost planets move most slowly and take the longest time to describe their orbits round the sun. So far as is at present known, the sun moves at about 200 miles per second, and requires something over 200,000,000 years to perform a complete revolution.

In the early days of astronomy our galactic system was thought to be the only system of stars in the sky, but we now know that it is only one of innumerable systems. If you look to the north of the star Beta, in the constellation of Andromeda, you will, if your eyesight is good, see a faint hazy patch. This is the object known as the Great Nebula in Andromeda. It looks at first like diffused starlight, as though a bit of the Milky Way had broken away—the astronomer Marius described it as looking like candlelight seen through a horn, while Herschel described it and similar objects as "shining fluid."

When this patch of light is viewed through a powerful telescope, a certain amount of detail begins to appear; we can see dark lanes across the background of light and notice a certain regularity in the form and structure of the object. But to study it properly we must photograph it with an exposure of many hours. Endless new detail now appears. The Nebula is found to be far larger than can be seen either by the unaided eye or by direct vision through a telescope; it is found to cover about 20 times as much sky as the full moon. The only part we can see with the unaided eye is a comparatively bright central mass, which is fuzzy in appearance and ill defined in outline. Round this is a detailed structure which lies hidden until it is photographed with a very long exposure.

Just as Galileo's telescope broke up the Milky Way into separate points of light which he at once identified as stars, so the modern high-power telescope breaks up the outermost regions of this Nebula into separate points of light. We know that these, too, are stars. Many of them do not shine with a steady light, but fluctuate in a very characteristic and quite unmistakable way with which we are very familiar, because many stars of our own system do precisely the same. Indeed stars of this type are so peculiar, so uniform in their behavior, and so similar to one another that we can estimate the distance of the Nebula from the apparent faintness of these stars.

Doctor Hubble, of the Carnegie Institution Observatory at Mount Wilson, has found it to be at such a distance that its light takes about 800,000 years to reach us.

There is no longer any room for reasonable doubt that, in its outer parts at least, this great Nebula in Andromeda is formed of a system of stars which is similar in its essential nature to our own system. It is not the only such system in the sky; millions of others can be observed.

Although these are of varied shapes and constitutions, it is found that the greater number of them can be arranged in a single sequence. At one end of the sequence are Nebulae consisting solely of round fuzzy masses, in which no stars are visible even in the most powerful telescope, while at the other extreme end we have clouds of stars such as our own system. Half way along the sequence are Nebulae, such as the great Nebula in Andromeda, which consist of a central fuzzy mass surrounded by stars, in which both the fuzzy mass and the stars are present, the former occupying the central and the latter the outer regions.

Like our own system of stars, these nebulae are generally flat in shape. The comparison of the cart wheel remains quite a good one, partly because many of these nebulae are known to be rotating and all are believed to be so; partly also because they often are found to have a thick central projection, corresponding to the hub of the wheel, while the rest of their structure is flat. The Great Nebula in Andromeda is of this cart-wheel shape, but it is rather disguised because we are neither looking at it full on nor edgewise on. If we could look at it full on, it would appear nearly circular in shape; if we could look at it edgewise on, it would appear rather more than a bright line of light; indeed it would probably look very much like the nebulae. N. G. C. 891, which is seen edge-on. From the angle at which we actually view it, it appears elliptical in shape.

We know all this because the various nebulae in the sky are, of course, seen at possible angles, so that we can study their structure as 3-dimensional solids. When we do this, we find that the sequence I have already described starts with perfectly globular nebulae and ends up with quite flat nebulae. The sequence is one of nebulae arranged in order of flatness.

It is easy to obtain a theoretical interpretation of this sequence. We know how an increase in the speed of rotation of a body is accompanied by a flattening of its shape. Our own earth, which is rotating slowly, is only slightly flattened, so that we describe it as orange-shaped. Jupiter rotates much more rapily (once every 10 hours), and as a result is much flatter in shape. Finally, astronomical bodies which are rotating very rapidly may be almost completely flat.

It is natural, then, to interpret our sequence of nebulae as one of bodies which are rotating at different speeds. And as we know that the speed of rotation of a body increases as it shrinks, we may reasonably conjecture that this sequence of nebulae corresponds to different stages of development. At the one end, we have the globular fuzzy mass of gas with little or no rotation; at the other end, we have the flat cart-wheel shape in which rotation predominates and governs the structure of the whole mass. A satisfactory confirmation of this is to be found in the fact that a number of these flat nebulae have been observed to be in a state of rapid rotation.

Now before Doctor Hubble had arranged the nebulae in sequence in the way I have described, I had tried to work out, as a problem of abstract mathematics, the sequence of configurations which a mass of rotating gas would assume as it cooled and shrank and, as a consequence, increased its speed of rotation. I arrived at a sequence of shapes which agreed almost exactly with that which Doctor Hubble subsequently found when he arranged the observed nebulae in sequence guided solely by the facts of observation, and deliberately putting theoretical considerations out of his mind. This leaves little room for doubt that the nebulae we see in the sky are members of this theoretical sequence, that they began as rotating masses of gas, and that we see them in various stages of development.

If a rotating mass consists of water or some entirely incompressible substance, an increase in the speed of its rotation merely increases its flatness. But compressibility of substance, such as comes into play with a gaseous nebula, introduces new features in addition to flattening.

At first the spinning mass simply flattens and assumes the shape of an orange. After a time a new feature appears—a pronounced bulge all round its equator. Finally this becomes so marked that the equator is merely a sharp edge; the rotating mass has assumed the shape of a double-convex lens as in N. G. C. 3115.

This configuration forms a noteworthy landmark in the evolutionary path of a nebula. Until it is reached, the effects of shrinkage can be adjusted, and are adjusted, by a mere change of shape—in spite of its reduced size, the rotating mass carries the same angular momentum as before by the simple expedient of rotating more rapidly and bulging out its equator. But we find that this is no longer possible when once this landmark has been passed.

Further shrinkage now involves an actual break-up of the nebula. This can no longer carry all its angular momentum as a single body; it is in the state of a fly-wheel which is rotating too fast for safety, and it relieves the situation by the ejection of matter from its equator. This brings us to the type of configuration shown in N. G. C. 5866, 4594, and 891.

We have so far spoken of the nebular equator as being of circular shape, as it undoubtedly would be if the nebula were alone by itself in space. But an actual bursting flywheel, of course, first breaks at its weakest point; if it were of absolutely uniform strength it would begin to break at all points of its circumference at once. In the same way, if the equator of the nebula were a perfect circle, and if the substance of the nebula were disposed symmetrically around its axis of rotation, the ejection of matter would necessarily start from all points of the equator simultaneously; there could be no conceivable reason why it should start at one point rather than any other.

In nature we do not expect to find perfect balances of this kind; if the main factors are of exactly equal weight, some quite minor factor invariably intervenes to turn the balance in one direction or another. In the present problem there could be no choice as between one point of the equator and another if the various minor factors were absent, but as soon as minor factors come into play, a discrimination at once takes place.

We have so far spoken of the rotating nebula as though it were alone in space. Yet it must have neighbors, and these will raise tides on its surface, just as the sun and moon raise tides on the surface of the rotating earth. Wherever the neighbors are, there will always be two points of high tide antipodally opposite to one another and two points of low tide intermediate between the two points of high tide. The equator will not be strictly circular, but slightly elliptical.

It is in all probability this tidal pull that determines the choice of points for the ejection of matter. Matter will be ejected at the points at which the gravitational pull of the nebula is weakest, and so at the two ends of the longest diameter in the equator of the nebula. After the nebula has passed its critical landmark, it ought still to retain the lenticular figure which formed the landmark, but with the additional feature of matter streaming out from two antipodal points on its equator.

This is exactly what we see in the types of nebulae which we describe as "spiral." In N. G. C. 5866 we see a nebula in which the ejection of matter is probably just beginning; we notice the bulge along the equator and a dark band which probably represents ejected matter which is already cooling. A more advanced state of development is shown in N. G. C. 4594; and a still later one in N. G. C. 891 in which the ejected matter already dwarfs the central nucleus in size, although probably not in total mass.

These are all photographs of nebulae seen very approximately edge-on. The well-known "whirlpool" in Canes Venatici (M. 51) is a spiral nebula which may be very similar physically to that shown in N. G. C. 891, but is seen face-on; we are looking along its axis of rotation. Again, the central nucleus occupies only a small part of

the picture. In two other spiral nebulae, M. 81 and M. 101, the evolution has proceeded still further, so much so that in the last of these there is very little nucleus left, and by far the greater part of what we see is what we believe to be ejected matter forming the spiral arms. In these last nebulae, we can see that the spiral arms proceed from two antipodal points, exactly as required by dynamical theory.

Yet this does not quite end the story, since the arms spread further into space than we should expect if rotation alone were responsible for their spreading. There must be other factors at work, and these we do not yet understand; the spiral formation of the nebular arms remains a mystery. It seems possible that the theory of relativity may explain it all to us in time, but it has not done so yet.

Gas set free out of an ordinary nozzle into a vacuum would immediately spread into the whole of the space accessible to it. Why then does not the jet of gas shot off from the equator of the nebula do the same?

The explanation is to be found in the gigantic scale on which this latter process takes place. As we increase the scale of the phenomenon, the mutual gravitational attraction of the particles of gas becomes of ever greater importance until finally, when we come to very large-scale phenomena (but before nebular dimensions are reached), gravitation overcomes the expansive influence of gas pressure and holds the jet together as a compact stream.

But dynamical theory predicts that when this happens, a further phenomenon ought also to appear. The influence of gas-pressure is in the direction of keeping the density spread out uniformly along the filament, while that of gravitation is towards making the stream condense into compact globules. When nebular dimensions are reached the latter tendency prevails, so that the jet of ejected matter breaks up into drops, much as a jet of water issuing from a nozzle does, although for a very different physical reason. In the photographs reproduced of N. G. C. 891, M. 51, M. 101, and M. 81 we can trace this process going on.

The nebula shown in N. G. C. 891 exhibits a lumpy or granulated appearance in its outer regions. In M. 51 this takes the form of pronounced condensations, and in the outer regions of M. 101 and M. 81 these condensations have further developed into detached and almost starlike points of light; indeed many of these are known to be stars or groups of stars.

Dynamical theory not only predicts that these globules of gas must form, but can also predict their sizes and masses. The calculation of the masses leads to an extremely interesting and significant result; the calculated mass of a single condensation proves to be approximately equal to the mass of the average star.

This provides an excellent confirmation of our theory, and gives, I believe, the key to the evolutionary process we have been considering—we have been watching the creation of the stars.

In N. G. C. 3115 we saw the raw material of the process—a gaseous mass of extreme tenuity, already molded, as a result of shrinkage and consequent increase of rotation, to the stage at which disintegration is about to commence. Further shrinkage takes place, and in N. G. C. 5866 and 4594 we see the ejection of the jets of matter from which the future stars will in due course be made. In N. G. C. 891 and M. 51 individual stars are beginning to form, although at present only as vague condensations in what is still a continuous nebula mass. Finally, each condensation forms a separate star, until the whole nebula is transformed into a star cloud. Thus the great nebulae prove to be the birth places of the stars.

Long before this complete evolutionary sequence was known, I had taken a preliminary step in the reverse direction, and had shown that the stars had in all probability been born out of a uniform mass of tenuous gas by a process which I designated "gravitational instability." If all the matter of our own system of stars were uniformly spread throughout the space occupied by the system, it would form a gas of density about 10^{-23}.

I showed that such a medium would be unstable, and that its instability would cause it to break up into condensations whose distances apart could be calculated mathematically, which calculation showed that these distances would be about equal to the actual average distance of the stars. Thus the single supposition that the stars had been born out of a uniformly spread mass of gas was found to explain at a single stroke why the stars all have approximately the same mass, and why these masses are what they are.

A similar situation has recently arisen with respect to the nebulae. In a telescope they appear to differ widely in shape, size, and brightness. But Doctor Hubble has shown that differences in size and brightness between nebulae of the same shape are almost entirely due to a distance effect. If all the nebulae were put in a row at the same distance from us, nebulae of the same shape would be found to have approximately the same dimensions and luminosity, while even nebulae of different shapes would exhibit only comparatively small ranges of dimensions and luminosity, especially the latter.

Because of this, it is possible to estimate the distances of all nebulae, even the very faintest, with fair accuracy; their faintness gives a measure of their distance. The faintest which can be observed photographically in the 100-inch telescope prove to be at the amazing distance of about 140,000,000 light-years. Some 2,000,000 nebulae lie within this distance.

Doctor Hubble finds that these are fairly uniformly spaced at an average distance of about 1,800,000 light-years apart. To construct a model, we may take 300 tons of apples and space them at about 10 yards part, thus filling a sphere of about a mile diameter. This

sphere is the range of vision of the 100-inch telescope; each apple is a nebula containing matter enough for the creation of several thousand million stars like our sun; and each atom in each apple is the size of a solar system with a diameter equal to or slightly larger than that of the earth's orbit.

Thus the arrangement of the nebulae in space reproduces on an incomparably grander scale the uniform spacing of the stars in our galactic system. It is natural to inquire whether the uniform arrangement of these larger masses can not again be explained by the supposition that the nebulae themselves came to birth as condensations produced by the gravitational instability of an earlier and even more tenuous mass of uniform gas. The test of the conjecture is, of course, by numerical calculation.

The masses of two nebulae are known with fair accuracy; one has 3,500 million times the weight of the sun, the other 2,000 million times. If all the nebulae have masses of about this magnitude, the average density with which matter is spread in space must be something like one gramme to 10^{30} cubic cms. The theoretical formulae show that instability would cause such a medium to form into condensations which would be at approximately equal distances apart, and that these distances would be of the order of hundreds of thousands of light-years. While the calculated distance comes out rather less than Doctor Hubble's observed distance of 1,800,000 light-years, yet it is near enough to it to make our conjecture seem reasonably probable.

These nebulae provide one of the great puzzles of astronomy. The theory of relativity suggests that the whole universe may be expanding, and recent astronomical observations, made mainly at Mount Wilson, have suggested that it is actually doing so, and this in no half-hearted way. If we may take the observations at their face value, the nebulae are even now rushing away from one another at almost incredible speeds. The last nebula which Mr. Humason investigated at Mount Wilson, at an estimated distance of about 105 million light-years, appears to be receding from the earth at the rate of 19,700 kms a second—about 12,300 miles a second! [Still more recently, nebulae at an estimated distance of 135 million light-years appear to be receding at about 15,000 miles a second.]

Some astronomers doubt whether these apparent recessions of the distant nebulae represent real motions in space or not. If they do, space must have expanded quite substantially since the nebulae first condensed out of the primeval gas.

The mathematical work of Lemaître and others has suggested that the mere condensing of the primeval gas into nebulae in the way just explained, would of itself suffice to cause space to start expanding. Before the expansion started there would be approximately the

same amount of matter in the universe as now, but it would be packed into a smaller space; the density of the primeval gas would be greater than we have calculated for it. Consequently, the distance apart of the condensations which ultimately formed nebulae would be less than we have calculated. After they had formed, their rushing apart would increase their distances, with the result that by now these distances would be nearly, but not quite, as far apart as those given by a calculation which ignores the expansion of the universe entirely.

The upshot of the whole matter is that, whether the universe is expanding or not, the actual condensations of a primeval gas ought to represent the present nebulae fairly well.

If this account of the origin of the nebulae is accepted, it becomes possible to trace out the mechanical evolution of the universe from its origin as a uniform gas spread throughout primeval space. We have in succession:

1. A uniform tenous gas of density of the order of 10^{-30} and of diameter at least thousands of millions of light-years.

2. Condensations developing in this gas at points hundreds of thousands, or perhaps millions, of light-years apart, and forming separate nebulae with masses of the order of thousands of millions of suns.

3. Condensations developing in turn in the arms of these nebulae, and forming stars with masses about equal to that of our sun.

Further, according to the " Tidal theory " of the origin of the solar system, we may add to this:

4. Condensations developing in the arms of gas pulled out from the stars by the tidal action of other passing stars, and forming bodies of planetary mass.

5. Condensations similarly developing in the arms of gas pulled out tidally from the planets, and forming bodies of a mass comparable with the satellites of the planets.

This scheme covers five complete generations of astronomical bodies, having masses of the order of 10^{55}, 10^{42}, 10^{34}, 10^{29}, 10^{25} gm., respectively, the birth of each generation from the preceding generation being through the agency of what I have described as " gravitational instability."

Owing to the repeated action of this agency, sometimes by itself, but more often in conjunction with other agencies, we see the universe gradually evolving from a single chaotically-spread primeval gas of extreme tenuity, down to comparatively small dense bodies such as our earth which form possible abodes for life.

THE VEIL NEBULA (N. G. C. 6992) IN THE CONSTELLATION OF CYGNUS, WITHIN THE CONFINES OF THE MILKY WAY

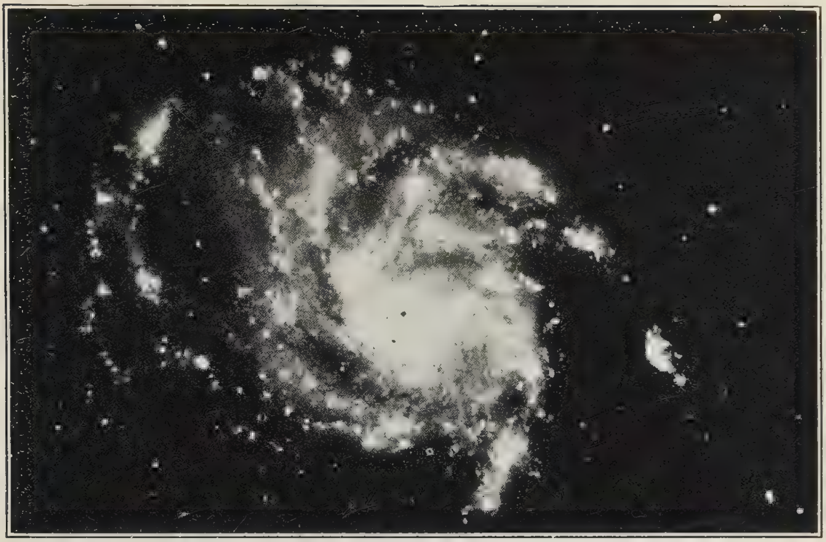
Nebulae, classified according to their characteristics, comprise dark nebulae, diffuse luminous nebulae, planetary nebulae, elliptical nebulae, and spiral nebulae. The first three classes are found only in or near the region of the Milky Way. Members of the last two classes lie outside the Galactic System (system of the Milky Way) and are called "extra-galactic nebulae," "island universes," "star-cities." The Veil Nebula belongs to the "diffuse" type and consists of dust and luminous gas.

1. THE GREAT NEBULA IN ANDROMEDA (MESSIER 31) TAKEN AT YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO

This, the most conspicuous of all spiral nebulae, lies far outside our Galactic System. It takes light about 800,000 years to reach us from it and 40,000 years to cross it from one side to the other.

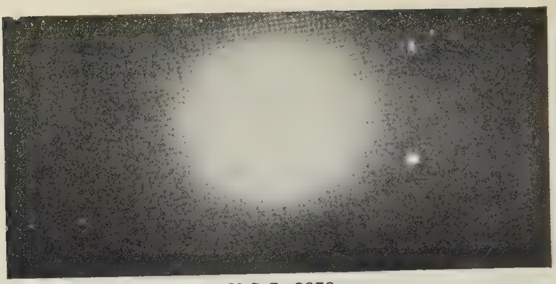
2. THE FAMOUS "WHIRLPOOL" NEBULA (MESSIER 51 IN CANES VENATICI)

This, the first nebula in which the spiral structure was discovered, is about 1,000,000 light-years distant.

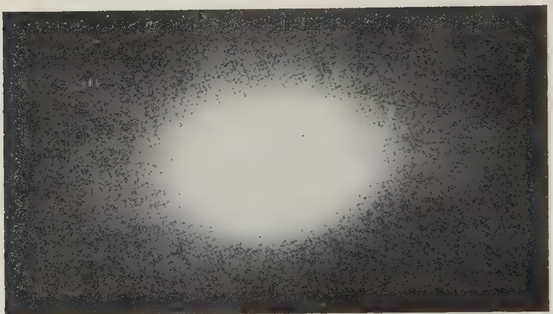


UPPER: MESSIER 101 IN URSA MAJOR. LOWER: A SPIRAL NEBULA IN THE BIG DIPPER (MESSIER 81 IN URSA MAJOR)

This is one of the most beautiful "star-cities" out in space, and was the first observed to be rotating. Its light takes 1,600,000 years to reach us. The central region is unresolved but in the outer portions swarms of stars are visible similar to the very bright stars in our own Galactic System.



N.G.C. 3379



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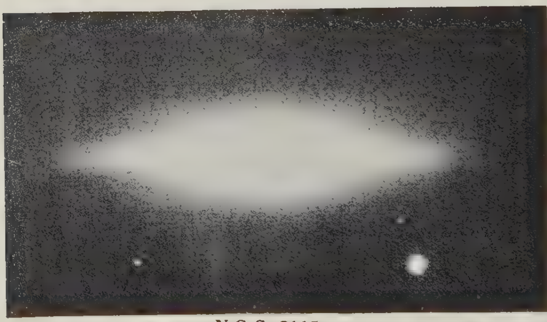
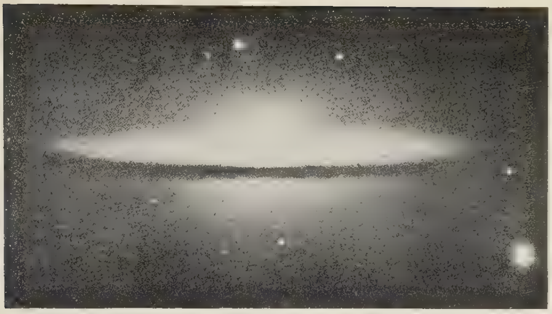


N.G.C. 3115

N.G.C. 5866

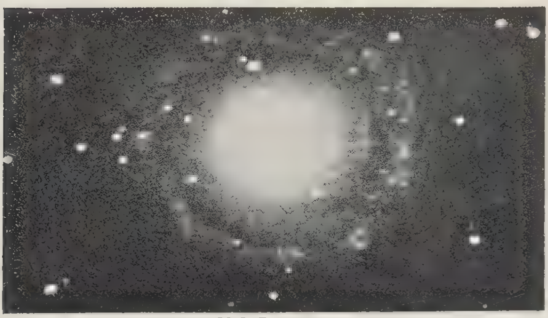
THIS PLATE AND THAT OPPOSITE SHOW A SEQUENCE OF SHAPES INTO WHICH THE GREATER NUMBER OF NEBULAE CAN BE ARRANGED

It begins with the globular fuzzy mass of gas having little or no rotation and ends with the flat cart-wheel type, like our own Galactic System, which rotates much more rapidly. It is believed that this sequence represents stages in the evolution of the universe. The last three in this series represent similar stages of evolution, being views taken at different angles.



N.G.C. 4594

N.G.C. 891



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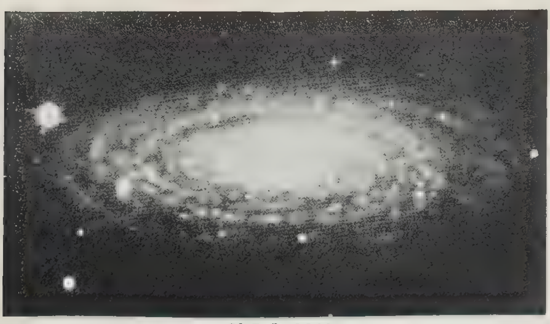

N.G.C. 2841

THE ROTATION OF THE GALAXY [1]

By A. S. Eddington

Plumian Professor of Astronomy in the University of Cambridge

Early in 1718 Edmund Halley communicated to the Royal Society the paper announcing his discovery of the proper motions of the stars, under the title "Considerations on the Change of the Latitudes of some of the Principal Fixt Stars." Referring to a comparison he had made of modern places of stars with the ancient observations collected in Ptolemy's Almagest, he wrote:

> I was surprized to find the Latitudes of three of the principal Stars of Heaven directly to contradict the supposed greater *Obliquity* of the *Ecliptick*, which seems confirmed by the Latitudes of most of the rest, they being set down in the old Catalogue as though the Plain of the Earths Orb[it] had changed its Situation, among the fixt Stars, about 20′ since the time of Hipparchus. . . . Yet the three Stars *Palilicium* or the *Bulls* Eye, *Sirius* and *Arcturus* do contradict this rule directly. . . . What shall we say then? It is scarce credible that the Antients could be deceived in so plain a matter, three Observers confirming each other. Again these Stars being the most conspicuous in Heaven, are in all probability nearest to the Earth, and if they have any particular Motion of their own, it is most likely to be perceived in them, which in so long a time as 1800 Years may shew it self by the alteration of their places, though it be utterly imperceptible in the space of a single Century of Years. . . . This Argument seems not unworthy of the *Royal Society's* Consideration, to whom I humbly offer the plain Fact as I find it, and would be glad to have their opinion.

Two hundred years have gone by, and now we are faced with a great accumulation of data concerning these apparent movements of the stars. This has been supplemented, mainly during the last 20 years, by extensive determinations of their velocities in the line of sight by use of the spectroscope. We have, therefore, a mine of material from which we are trying to learn what we can of the nature of the motions of the stars as a system and to reach some kind of dynamical theory of what is going on. A caution must be given at the outset. According to modern views the dimensions of our galaxy are immense; and although our survey of stellar motions extends over

[1] Reprinted by permission from The Rotation of the Galaxy, being the Halley lecture delivered on May 30, 1930, by A. S. Eddington, Oxford University Press, 1930.

a region containing perhaps 10 to 100 million stars, this is but a small part of the whole. We have to take a risk in inferring the nature of the complete system from the small sample within reach.

Throughout the nineteenth century astronomers working on stellar motions concentrated their attention on one main theme—the solar motion, or velocity of our sun as an individual star with respect to the system as a whole. For our present discussion of the system of the stars this has no particular interest, being merely a distorting factor in our outlook which is sometimes troublesome to eliminate. We are concerned with the stellar motions remaining after our own translational velocity has been allowed for; they are by no means those of an unorganized crowd. By later researches four leading peculiarities have been discovered. I give them in historical order:

(1) Star streaming, i. e., a tendency of the stars to move to and fro along one particular axis in space rather than in directions at right angles to it.

(2) A strong correlation between the velocity and the physical characteristics of the stars. For example, stars classed as of "late" spectral type have a higher average speed than those of "early" type.

(3) Stars of exceptionally high velocity (greater than 80 km per sec.) are found to be moving exclusively toward one hemisphere of the sky.

(4) An effect rather complicated to describe which we interpret as evidence of rotation of the whole system. This is the main theme of my lecture.

In conjunction with these results we have to consider a matter of common knowledge inferred from the apparent distribution (not the motions) of the stars. Our stellar system has a very oblate form. It is believed to be almost a disk—resembling the spiral nebulae seen abundantly in the vast universe beyond the confines of our galaxy.

NATURE OF THE ROTATION

The discovery of the fourth effect and the interpretation placed on it are due to J. H. Oort of Leiden. Among other investigators should be mentioned especially B. Lindblad, who had been developing the hypothesis of galactic rotation for other reasons, and J. S. Plaskett, to whom we owe the most convincing evidence.

It will help us to understand what kind of indication of rotation we might look for in a system of stars, if we transfer our attention for a moment to a phenomenon nearer home, namely Saturn's rings. These have a rough resemblance to the disklike form attributed to our galaxy. At one time there was a division of opinion as to whether the rings were solid structures or whether they consisted of swarms

of small particles. In a famous mathematical investigation, which is one of the classics of celestial mechanics, Clerk Maxwell showed that the solid type of ring was dynamically impossible; it would be unstable. The only permissible constitution was a swarm of separate bodies. Many years later Maxwell's theory of the ring was strikingly confirmed by Keeler; and it is his method of confirmation which especially interests us. If a solid ring rotates, its outer edges must necessarily travel faster than the inner edge; on the other hand, if the ring is a swarm of meteoric particles, they will follow the same rule as the planets in the solar system, viz. the inner particles must travel faster in order to counterbalance the stronger gravitational pull of the planet. Keeler found by spectroscopic observation that the inner edge of Saturn's ring travels faster than the outer edge, indicating therefore that it is a swarm of particles and not a solid arch.

In the galaxy we know that we are dealing with a swarm of particles—stars—and not with a solid ring. Consequently, we may expect that it will rotate after the manner of Saturn's ring, the inner stars traveling faster than the outer stars. This is fortunate for our hopes of detecting rotation. For investigating this problem we are dependent almost entirely on observed radial velocities. Radial velocity means the approach or recession of other particles from our own particle (the sun); clearly radial velocity measurements would be unaffected by and would not detect a rotation like that of a solid body in which all particles preserve the same distance apart. It is important to bear in mind that the effect manifested by the radial velocities, and detected and measured by Oort, is not the absolute rotation but the differential rotation or Saturn's ring effect—the increase of angular velocity as we go toward the center of the system.

Figure 1 shows a portion of the galaxy rotating about a center situated far outside the diagram, the rotation being faster as we go toward the center. We must ask, How will this appear to an observer in the midst of the region? He will appreciate only the relative motion of the different parts of the system. In Figure 2 we have reduced him to rest by applying to all parts of the region a velocity equal and opposite to his own.

The observer is armed with a spectroscope and measures velocities (relative to himself) in the line of sight. We see from Figure 2 that there are four directions in which this line of sight velocity will be zero, viz., to the right and left (approximately) because there there is no relative motion, and up and down the page because there the relative motion is entirely transverse to the line of sight. But in diagonal directions an effect will be observed; the stars seen in both directions along one diagonal are receding and those seen along the

other diagonal are approaching. Figure 3 shows the resulting distribution of radial motion (ignoring the transverse motion which is

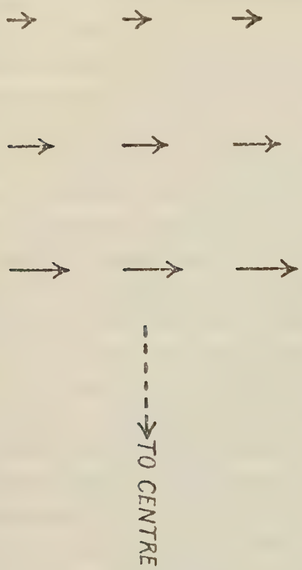

Fig. 1.

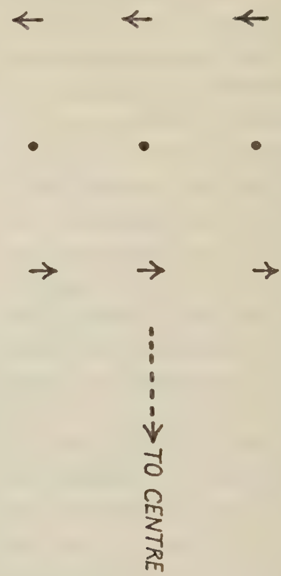

Fig. 2.

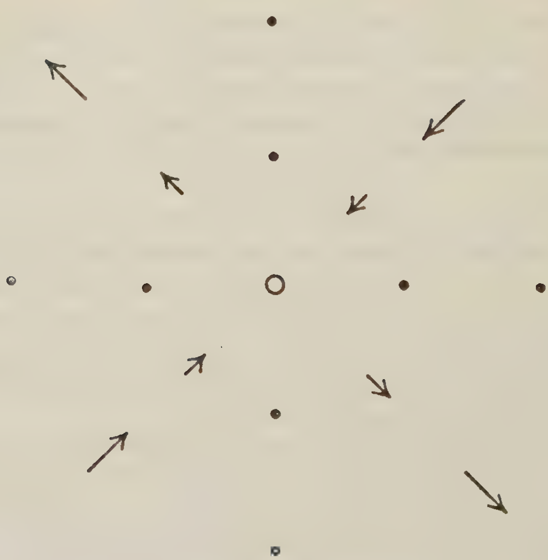

Fig. 3
Distribution of radial velocity

not detected by the spectroscope). It will be seen that the distribution of motion is of the kind which distorts a square into a diamond.

This distortion comes from the shearing effect when the inner part of a ring travels faster than the outer part.

Mathematically we can describe this distribution by saying that, when the stars are arranged according to galactic longitude l, their observed radial velocities contain a term $C \sin 2(l-l_0)$, where l_0 is the longitude of the center of the system. Moreover, it is clear that the effect is greater for greater distances being approximately proportional to the distance of the stars considered from the observer. We therefore express the term as

$$Ar \sin 2(l-l_0),$$

where r is the distance of the stars examined, and A is a constant.

The stars have their own individual motions superposed on the general rotation of the system, and we can only expect to discover this effect if we average out the individual motions by taking means for a considerable number of stars. Owing to the increase of effect with distance it is best to search for it in the more distant classes of objects. It may be said at once that the search is successful. The expected distribution of velocity is found in all classes of objects that could be expected to show it, and they agree among themselves both as to the magnitude of the effect and as to the direction in which the center of the galaxy is situated.

OBSERVATIONAL EVIDENCE

Through the researches of Harlow Shapley, the center of our galaxy had already been located in the direction of the great star clouds of Sagittarius—the richest part of the Milky Way. He deduced this from the distribution of the most distant galactic objects observable, particularly the globular clusters, which may be supposed to outline the shape of the system. The exact center can not be found with any high accuracy, but the position generally adopted is in 325° galactic longitude. Oort's method of deducing it from the rotation effect is entirely independent; it generally gives a rather higher longitude 330°–335°, but the difference is within the probable uncertainty of the determinations.

As already stated, the magnitude of the effect increases with the distance. For stars distant 1,000 parsecs[2] it amounts to 17 km per sec., that is to say the stars seen at this distance in one part of the sky are in the mean moving toward us at 17 km per sec., whereas those 90° away are moving from us at the same rate. For other distances the effect is in proportion—8½ km per sec. for 500 parsecs

[2] 1 parsec = 3.26 light-years.

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distance, 34 km per sec. for 2,000 parsecs, and so on. This provides what may ultimately prove to be a valuable means of finding the mean distance of a class of objects when it is not determinable by older methods; for if we measure the magnitude of the rotational effect we can at once write down the corresponding distance. To illustrate this I will refer to a remarkable investigation by Plaskett and Pearce.

Their research dealt with the radial velocities of about 250 stars of the most distant type known. They wished to sort these into groups according to distance; but since the stars were far beyond the range of ordinary methods of distance determination this separation presented some difficulty. It is not much use to sort them according to apparent brightness, because brightness is a poor criterion of distance. The authors availed themselves of a method developed recently by Otto Struve. We are looking at these stars through a thin veil of cosmical cloud. The cloud leaves its mark on the light, producing certain narrow absorption lines in the spectrum of the star. If the absorption is intense it is a sign that we are looking at the star through a great thickness of cloud—that the star is very remote. By this criterion Plaskett and Pearce divided the stars into three groups showing low, medium, and high absorption, respectively, which must correspond presumably to small, medium, and great distance.

In the following table the third column gives the magnitude of the rotation term for each of the three groups and the fourth column gives the deduced distance (the proportion being 17 km per sec. per 1,000 parsecs as already stated.) It will be seen that Struve's criterion has been successful; or at least that Oort's and Struve's methods of estimating distance (both of which must be regarded as on trial) confirm one another.

Absorption	Number of stars	Stars		Cloud	
		Rotation effect (km per sec.)	Distance (parsecs)	Rotation effect (km per sec.)	Distance (parsecs)
Low	90	10.2	600	5.0	295
Medium	79	14.5	850	6.9	405
High	43	27.5	1,620	13.7	805

Turn now to the fifth and sixth columns, in which the same analysis is applied not the stars but to the motions of the cosmical cloud. The velocity of the cloud can be measured in the same way as that of a star from the Doppler shift of the spectral lines which it absorbs; but, of course, our measurement refers not to the whole cloud but to the particular part of the cloud responsible for the absorption.

If the absorption occurs uniformly in the cloud, the mean distance of the stretch traversed by the star's light should correspond to halfway. The distance of the veiling cloud should, therefore, always come out to be half the distance of the corresponding stars. A glance at the table will show how closely this is fulfilled. To speak frankly, I should have been better pleased to see more discordance, since the closeness must to some extent be put down to rather outrageous luck—as the authors indeed recognize.

The transverse proper motions can be examined for differential rotation in like manner, but I am skeptical as to whether they add very much to the evidence. In treating the radial velocities we have gained greatly by using the most distant stars and, granting that sufficiently luminous stars can be found, there is no more difficulty in determining radial velocities at 2,000 than at 20 parsecs distance. But proper motions depend on measurements of arc, and what we gain through the magnification of the effect by distance we lose in the reduction from linear to angular displacement. The effect on the apparent angular motion is thus the same at all distances and remains always on the verge of what is detectable observationally. However, so far as the evidence goes it is favorable to the theory. An extensive investigation by Sir Frank Dyson gave correctly the center in longitude 330°, but the magnitude of the differential rotation was somewhat smaller than that deduced from the radial velocities. He pointed out that the analysis also indicated certain larger terms not explicable by rotation—a fact which seems to spoil the significance of the result.

When I decided to lecture on this subject, I thought I was going to describe the newest of the various methods employed in our search for information about the stellar system. I was mistaken; it is the oldest. Vixerunt fortes ante Agamemnona multi. Precisely this method was employed by Gyldén in 1871.[3] Using the proper motions then available he discovered the double-period term $C \sin 2(l - l_0)$ and explained it just as we have done. To make the conclusion more convincing he made a test of the validity and efficiency of the method by applying it to the apparent motions of the asteroids, using them as a model for illustrating differential rotation as I have used Saturn's ring. From the motions of the asteroids he deduced the direction of the center of the system, viz, the sun; his error was about 6°. That would be one way of finding the sun again if ever it ceases to be visible! Returning to the stellar system Gyldén remarked that a definitive determination of the center was not at present practicable because the common rotational motion was pre-

[3] Indications of Laws Governing Stellar Motions (in Swedish) Öfvers. K. Vetensk. Förhandl., vol. 28, p. 947. I am indebted to Professor Lindblad for the reference and information.

sumably in the plane of the Milky Way, and proper motions for the part of the Milky Way in the southern hemisphere were lacking. He had to content himself with such indications of the center as could be found from analysis in the plane of the Equator. It is true that the direction provisionally given by Gyldén for the center of the system is opposite to that now generally accepted; but that is because the double-period term fixes only the line to and from the center, and does not decide between the two possible antipodal positions. He concluded: "At all events there remains an indication that the motions of the stars have something in common, and that they are not so at random as many astronomers have been inclined to assume."

By these researches we find the change of velocity in going toward or away from the center; we do not learn the actual velocity at any point. A possible way of discovering this is by observing the globular clusters which can be seen at very great distances up to and beyond the center of the galaxy. By their great spread they will have a mean motion fairly representative of the system as a whole, whereas our stellar observations are limited to a comparatively small region and give the local motion. The difference represents the mean speed at which the stars in our neighborhood are traveling through the system. The result of this determination can not at present be regarded as very accurate, but is sufficient to show that our orbital speed is large, probably between 200 and 300 km per sec.

CONSEQUENCES OF THE ROTATION

We have thus to recognize that for a broad cosmical survey the standard of rest to which we have been in the habit of referring all our measured velocities is an inappropriate one. We realized long ago that it was too crude to take the sun as standard, and we have referred velocities to the " mean of the stars "—meaning the stars which come within range of ordinary measurements. Now we have to recognize that this also is a very local standard affected by large orbital velocity, and we must apply a further correction of two or three hundred kilometers per second to reduce to the center of our galaxy. I am afraid it is too much to hope that this will be our final resting place; we see in outer space some hundreds of thousands of other galaxies which will claim a share in defining a universal standard. Meanwhile the shift of our viewpoint to the center of the galaxy has produced one great improvement; it has brought better order into the motions of the spiral nebulae. It is the general rule that spiral nebulae are receding from us at very high speed; the greater the distance, the higher the speed. But the rule was marred by two notable exceptions. As these two are the largest

and almost the nearest of the spiral nebulae we do not expect any decided recession in their case; but it was disconcerting to find that they were approaching us with high velocity. We now learn that this apparent approach is merely the reflection of our own high orbital speed in their direction, and when we refer their motion to the center of the galaxy nothing very serious remains.

At this point we can weave into the picture another feature of stellar motions mentioned in the list on page 240. High velocity stars, i. e. stars with speeds greater than about 80 km per sec.,[4] always move towards one hemisphere of the sky. Why are there none moving the opposite way? The direction favored by the high velocity stars turns out to be just the reverse of the direction of our orbital motion, so that when we have regard to orbital motion we must think of them as the extreme laggards—lagging behind the majority of the stars by 80 km per sec. or more. Had they been going the other way, they would have been an advance guard hurrying ahead of the others. Here lies a significant difference; stars can lag behind without any serious consequences, but if a star goes too fast the attraction of the system will fail to control it and it will escape.

To fix ideas, let us take the orbital velocity in our neighborhood to be 200 km per sec. The so-called high velocity stars are lagging behind by 80 km per sec. or more, so that their speed about the center of the system is no more than 120 km per sec. Had there been any high velocity stars in the opposite direction, i. e. gaining 80 km per sec., they would have had an orbital speed of 280 km per sec. or more. No such stars are observed, and the reason is plain. It is a well-known rule that for particles moving under the attraction of a mass-center the velocity for escape is $\sqrt{2}$ times the velocity for a circular orbit; so if 200 km per sec. is the appropriate speed to keep the average star moving in a circle about the center of the galaxy, 200 $\sqrt{2}$ or 280 km per sec. is the speed which will cause it to leave the system altogether. The asymmetry of the high velocity stars—the fact that none are found moving towards one hemisphere—is an inevitable consequence of rotation. Such stars (if they ever existed) must have escaped from our system long ago.

The magnitude of the Oort effect and the orbital speed of the stars in our neighborhood together determine our distance from the center of the galaxy. As the latter datum is at present badly determined, I will give the result for several different adopted values. The mass of the system which controls the orbital motion can also be calculated.[5]

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[4] The velocity is referred to the local standard, viz, the mean of the stars in our neighborhood.

[5] The calculation is on the assumption that the main part of the mass of the system is concentrated near the center. If the mass is more generally diffused, the distance and controlling mass are somewhat reduced, but the order of magnitude is not greatly altered.

Assumed orbital speed (km per sec.)	Distance of center (parsecs)	Mass of system (sun's mass=1)
150	6,600	33,000,000,000
200	8,800	78,000,000,000
250	11,000	150,000,000,000
300	13,200	260,000,000,000
350	15,400	420,000,000,000

These results may be compared with estimates arrived at in an entirely independent way. The distance from the center seems to be of the right order of magnitude. Thus Shapley from his work on globular clusters located the center of the galaxy at 13,000 to 25,000 parsecs distance. The mass also, although higher than most current estimates, is not unreasonably large. By extrapolating the results of actual counts of stars, Seares and van Rhijn obtained a total of 30,000,000,000 stars in the galaxy. Since dark nebulae hide our view, more especially in the direction of the center, it is doubtful whether their survey comprehended the whole system, and the number may well be greater. The average mass of a star is probably not more than half the mass of the sun, but there is in addition the mass of the cosmic cloud and of the bright and dark nebulae to be brought into account.

How long does the galaxy take to make one complete revolution? The answer is about 250 million years. We can state the figure fairly definitely because it does not depend on any of the more doubtful estimates; the only datum needed to determine it is the magnitude of the Oort effect. It should, however, be added that since the inner parts of the galaxy rotate faster than the outer parts, there is no one period of revolution for the whole; the period 250 million years refers to the zone in which the sun lies. It is important to notice that the galaxy has made five or six rotations within geological times. The sun and earth were away on the far side of the center 100 million years ago—a time which geologically does not seem to be very remote.

We may now sum up the evidence for the hypothesis of a rotation of the galaxy. An effect resembling differential rotation is observed in all classes of distant stars and also in the cosmic cloud pervading the system. These give consistent indications of the direction of the center and they agree also as to the amount of differential rotation. The evidence from proper motions has small weight, but for what it is worth it supports that derived from spectroscopic radial velocities. The dimensions and total mass of the galactic system, inferred from this effect, are reasonably consistent with current estimates based on other data. Our large orbital velocity of 200–300 km per sec. is confirmed to some extent by observations of globular clusters

and spiral nebulae which are too remote to partake of it. Further, since stars with a large individual velocity additive to the general orbital velocity would escape from the system, we have a simple explanation of a well-known phenomenon, viz, that high velocity stars favor a direction now identified as that opposed to the orbital motion. Finally, the very oblate shape of the stellar system is strongly suggestive of rapid rotation; and in the spiral nebulae, which are believed to be patterns of our galaxy, the rotation can be directly observed and measured.

The evidence seems convincing; nevertheless a thread of insecurity runs through the whole fabric. It is the old story—our conclusions rest mainly on observations of the northern celestial hemisphere, and the southern observations make a poor counterweight. This is a common complaint in all discussions of stellar statistics; but I think that in none is it so serious as in the determination of galactic rotation. For this the most useful data have been provided by the Dominion Astrophysical Observatory (British Columbia), which by reason of its rather high latitude is less able than some of the other northern observatories to poach on the southern hemisphere. In the investigation of Plaskett and Pearce, whose results I have quoted (p. 244), out of 250 stars only 4 were between 193° and 343° galactic longitude; a stretch of one-third of the whole circuit was unrepresented by a single star. This is the operation which Kapteyn used to describe as "flying with one wing." By mathematical dexterity the required constants of rotation have been extracted from the lopsided data; but no mathematical dexterity can avert the possibility that the neglected part of the sky may spring an unpleasant surprise. As a spectator I watch the achievements of our monopterous aviators with keen enthusiasm; but I confess to a feeling of nervousness when my turn comes to depend on this mode of progression.

THE DYNAMICAL PROBLEM

The admission of galactic rotation must modify our earlier views in a way which is not always sufficiently appreciated, and I think that there are many who retain an incongruous mixture of the old with the new ideas. The distribution of the stars is far from regular and it has been customary to think of the galaxy as subdivided into a number of vaguely defined aggregations or star clouds. Particular attention has been paid to a supposed aggregation in which the sun is nearly central; this is known as "the local cluster." Charlier attributed to it a diameter of 700 parsecs with a thickness about one-third as great; others have attributed greater dimensions. (It is sometimes hinted that investigators place the boundary of the local cluster suspiciously near the distance at which their observational

data fade away.) There can be no permanent cluster of this kind if the hypothesis of galactic rotation is accepted. Taking the minimum estimate of 700 parsecs diameter, the differential rotation is such that the inner edge of the cluster will make eight revolutions whilst the outer edge makes seven. Obviously a compact cluster will be quickly sheared into elongated form, ultimately to be drawn out into a complete ring. It is not legitimate to reply that their mutual gravitation will help to keep the stars of the local cluster together and perhaps override the forces of dispersal; for it is from these very stars that the observational evidence of the dispersing motion has been derived. That the distribution of stellar motions around us is such as would elongate and disperse a local cluster is an immediate observational conclusion—independent of our interpretation of it as evidence for rotation of the galaxy. It would be contrary to observation to deny the existence of irregularities of distribution like star clouds, but I think they must be regarded as transitory eddies in a whirlpool, which form and dissipate continually.

The results now before us raise an interesting dynamical problem; but before entering on it, it is necessary to be clear as to our guiding principles. One possible aim would be to develop a theory showing how the present complexities of motion and distribution of the stars might have arisen by natural evolution from some simpler and more uniform initial state satisfactory to our sense of fitness; but that is probably too ambitious a program at present. In most investigations the guiding idea has been that, whatever initial formation the stellar system may have developed from, it has at any rate been a very long while about it. Consequently, if we trace back its history a few thousand million years we ought not to find much change. Accordingly, the mathematical conditions of the problem are assumed to be that the stellar system is (approximately) in a steady state.

It may perhaps be thought that too much of a fetish has been made of the "steady state" in the various mathematical theories of the galaxy, but that is a misconception of their aim. Although formally the mathematician may seem to be designing a model stellar system which will last for ever, that is only his way of tackling the design of a model which will last long enough to fulfill the obvious requirements of the problem. Geological time swallows up at least 1,500 million years; we must allow a reasonable margin beyond that for the evolution of the solar system, say 3,000 million years altogether. The minimum requirement of our model system is that it will keep going for that time without collapse. Actually we are hard put to it to invent a galaxy with even this limited degree of permanence, which shall at the same time embody the main features of stellar motion and distribution enumerated on page 240. As for

those who dabble in the long time scale of billions of years now fashionable (and I have to confess myself one of them) we must simply ignore them. Whatever the study of individual stars may bring forth in its favor, the evidence of galaxies and of systems of galaxies is dead against so leisurely a rate of progress. The problem of the galaxies is unapproachable except from the standpoint that the material universe is a much more evanescent affair.

The term " steady state " is used with two distinct meanings, and we must further define which meaning concerns us here. Starting with an entirely irregular distribution of stars and stellar velocities, there are two stages in the approach toward ultimate equilibrium. The first stage is accomplished when the orbits described under the general attraction of the whole mass have become so distributed as to preserve the shape and density unaltered; the " density of population " at any point then remains steady although the individuals are moving to and fro. This is called dynamical equilibrium. But these orbits are from time to time perturbed by chance approaches of the stars to one another, and the distribution slowly changes until a special form of dynamical equilibrium is reached with the additional property that these haphazard perturbations produce no change on balance. This is called statistical equilibrium. We shall see presently that the steady state of the stellar system is that of dynamical equilibrium, and not the ultimate statistical equilibrium which belongs to a far distant future.

The rate of approach to equilibrium, whether dynamical or statistical, may be measured by a " time of relaxation "—a time in which deviations from the equilibrium distribution decay to about half their original magnitude. For statistical equilibrium the time of relaxation is estimated by Jeans and Charlier at 10^{14} to 10^{16} years. This is so great compared with even the most extreme time scale that we may put statistical equilibrium outside our thoughts. But the time of relaxation toward dynamical equilibrium is of the order 1,000 million years. Remembering that in our part of the system individual stars go right round their orbits in 250 million years, any irregularity will in general be dissipated all over the system in something like that period. We, therefore, expect to find dynamical equilibrium fairly complete.

In a series of three papers in 1913–1915 I discussed the conditions for a steady state (dynamical equilibrium) of a system of moving stars, including the case of a flattened system like our galaxy, both with and without rotation. Re-reading these papers I do not find anything to modify in the mathematical investigations, except that later writers have found short cuts to some of the results; nor do they seem to need much extension or adaptation to cope with the prob-

lems that have cropped up since then. But when I turn to the efforts I then made to fit the theory to the observed properties of the system, it is like a glimpse of the middle ages. Is it possible that only 15 years ago we thought the stellar universe was like that! With some misgiving I found I must place the sun at least 500 parsecs away from the center of the system; but I did not expect to be believed. Nowadays 7,000 parsecs is the minimum estimate. I was perturbed to find that on the rotation theory I must ascribe to our neighborhood an orbital velocity as great as 25 km per sec.; in excuse I offered a suggestion as to how the differential effects of so rapid a rotation might happen to be concealed. Now we admit an orbital velocity 10 times greater, and claim that its differential effects are not concealed but strikingly manifested. It almost looks as though with a little more courage—a little less reluctance to rend the then accepted fabric—the purely dynamical theory might have forecast the changes that have since been made as the result of observation; I doubt, however, if that would have been justifiable without some additional facts to build on. But I take warning not to be in too great a hurry to stretch the dynamical theory to fit even our present enlightened ideas. I seem to hear the voice of the Halley lecturer of 1945 repeating my remark, "Is it possible that only 15 years ago we thought the stellar universe was like that!"

In the past 15 years the accepted dimensions of the galaxy have been enlarged tenfold, and we have to start the comparison of theory with observation anew. There is, however, one result which seems to have been able to survive all vicissitudes, viz., the period of revolution of the stars in their orbits around the center. The period adopted in 1914 was 300 million years, which is close enough to the 250 million years deduced from the Oort effect.

STAR STREAMING AND PERMANENCE

In 1915 the main stimulus to dynamical investigation came from the phenomenon of star streaming—the tendency of the stars in our neighborhood to move to and fro along one particular line rather than at right angles to it. Ever since this was pointed out by Kapteyn in 1905, it has been recognized as the most conspicuous peculiarity of the observed proper motions. It might be a merely local arrangement due to two independent clouds of stars meeting and passing through one another; on the other hand it might have a wider significance as part of the general law of motion of the whole galaxy. A suggestion was put forward by H. H. Turner that the line of star-streaming points to the center of the galaxy; if so, the motion seems to be a very natural one. He pointed out that if we examined in the same way the motions of the comets in the solar system they would show a preferential motion in the radial direction

towards and away from the sun. We do not see anything odd in this distribution of cometary orbits; equally we may anticipate a preferential motion of the same kind in the orbits of the stars.

One doubt arose in connection with this suggestion which needed theoretical examination. If the main lines of stellar traffic all converge to the center of the system, will there not be a frightful congestion at the center? It is true that the radial roads are laid down as preferential only, but, allowing for the divergence of individual stars from the general direction, there would still seem to be fear of a congestion in the inner part of the galaxy so great as to lead to trouble. Mathematical calculation has, however, dispelled this fear. One way of relieving congestion is to speed up the traffic at the spot concerned. That applies to the stellar system; the stars which approach the center put on speed under the gravitational attraction, and by clearing out of the neighborhood as quickly as possible keep down the density to a tolerable value. Apparently, then, nothing stands in the way of adopting Turner's suggestion

But Kapteyn and others who followed him pinned their faith to a different theory. They believed that the line of star streaming was transverse to the radius; this would mean that the stars tend especially to move in circular orbits about the center like planets, only (unlike the planets) they go either way round indifferently. This seems a very artificial disposition, and it could scarcely be regarded as an explanation of star streaming in the sense that Professor Turner's suggestion was. However, the first question is not which scheme affords the better explanation but which gives a correct representation of the facts. Now that there is general agreement as to the direction of the center, we can answer at once; the direction of star streaming is radial, or nearly radial,[6] as Turner supposed. But the observational decision in favor of radial star streaming is recent, and theory had first innings in the contest Radial versus Transverse star streaming.

Adopting the specification of star streaming, introduced by Schwarzschild, I was able to show rigorously that in a steady system with star streaming the preferential motion must necessarily be radial. Shortly afterwards J. H. Jeans showed rigorously that in a steady system with star streaming the preferential motion must necessarily be transverse.[7] I doubt whether many spectators of the game understood how to interpret the score of "one all" which was the apparent result of the contest. Possibly they thought it was just a case of two theorists contradicting one another as usual. But

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[6] The most trustworthy determinations give a difference of about 10° between the line of star streaming and the radius; it is difficult to decide whether the discrepancy is large enough to be significant.

[7] Unless the system is spherical—an exception irrelevant to the study of our own highly oblate galaxy.

actually the two investigations were complementary; the one excluded all save radial star streaming, the other excluded all save transverse star streaming. Between them they established that neither radial nor transverse nor any other direction of star streaming is compatible with strict dynamical equilibrium. It seems to be clearly established by observation that radial star streaming exists; but Jeans's investigation indicates the price that must be paid—the galaxy can not be in a steady state. Nor would a transverse direction of star streaming have saved it; the determination of the direction merely decides which horn of the dilemma our galaxy shall impale itself on.

Here lies the chief difficulty in pursuing dynamical theories of the galaxy. A perfectly steady model having been proved to be impossible, we must seek some compromise among the incompatible conditions for permanence, which will give a semipermanent model satisfying our minimum requirements of duration. I do not think that much serious progress has been made toward such an adaptation of the steady state theory. Oort and Lindblad have obtained certain theoretical relations between the intensity of star streaming (the prolateness of the Schwarzschild velocity-ellipsoid) and the magnitude of the differential rotation and found a rather impressive agreement with observation; but it may be urged in criticism that they have selected one out of a number of incompatible conditions for a steady state, and it is not at all clear why this (rather than the rejected conditions) should be retained in the appropriate compromise. My own impression is that it is the least essential of the conditions for longevity.

ROTATION OF THE COSMIC CLOUD

My survey of the dynamics of the galaxy must necessarily be superficial, since it would be idle to enter into details without recourse to mathematical formulae. I should like, however, to refer to an aspect of the problem which has not as yet received much attention. The recognition of a cosmic cloud of rarified gas extended through interstellar space and sharing in the rotation of the galaxy opens up a new field of theoretical investigation; and the dynamical equilibrium of the cloud is a problem equally important with, and considerably easier than, the dynamical equilibrium of the stellar configuration.

We find that in our own neighborhood the motion of the mean of the stars agrees with the motion of the cosmic cloud; the difference can not be put higher than 2 or 3 km per sec. Moreover, it appears that this agreement is not confined to our immediate neighborhood, but extends at least 1,000 parsecs away from us, since Plaskett's investigation of the differential rotation of the cloud covers this range.

The coincidence was not unexpected so long as both were regarded as "at rest," but it takes on a new significance when it is understood to mean that both stars and cloud are moving about the center of the galaxy with the same orbital velocity (of order 250 km per sec.). That they should agree to within 1 per cent is indeed surprising; and I think that the explanation of this coincidence should take precedence over many of the other aims of dynamical theory.

It seems impossible to admit any kind of interaction which would tend to drag along the stars with the cloud or the cloud with the stars. We have to regard them as two intermingled systems independent in all respects except that the controlling gravitational field is the same for both. If there is any community of motion it must be because the same causes have operated in both and not because one has constrained the other. At first sight a similarity seems plausible. We often treat the stellar system as a glorified gas with stars for molecules. Is it not then a case of two "gases" finding their own conditions for equilibrium independently? Why should we be surprised that they both hit on the same solution? Nevertheless, I admit that I am surprised; the reason is that the two gases differ enormously in viscosity.

An atom in the cosmic cloud may in the course of its wanderings expect a collision with another atom about once a year; in that time it traverses a path about equal to the distance of the earth from the sun. This is a long free path according to ordinary standards, but it is insignificant in the scale of the stellar universe. On the other hand the free path of a star is practically infinite; it can go hundreds of times around its orbit from one side of the galaxy to the other without appreciable risk of deflection. The length of the free path determines the viscosity of a gas. The viscosity of the cosmic cloud is negligible for astronomical purposes; the viscosity of the star-gas is enormous. In fact the stellar universe, regarded as a gas, is the stickiest thing you could possibly imagine.

The theory of a rotating nonviscous gas is familiar, and it can be applied directly to the cosmic cloud. We can at once derive an important result; the motion of the cloud must correspond almost exactly to that of a particle revolving in a circular orbit about the center. A slight deviation—if only a few km per sec.—would set up an enormous density gradient in the cloud, so that in one or other direction the stars would be embedded in a solid jam of cloud-atoms.[8]

[8] I ought to mention that the time of relaxation toward dynamical equilibrium is longer for the cloud than for the stars owing to the lower velocity of the particles. We may say that the velocity of sound in the cloud (about 3 km per sec.) is less than the velocity of sound in the star-gas; and accordingly the pressure-waves which level out the distribution of cloud matter take a longer time to travel through the galaxy than those which level out the distribution of stars. It is, therefore, possible that if we adopt a short-time scale the cosmic cloud may not yet have reached the dynamical equilibrium assumed in my discussion.

There is, perhaps, a difficulty in explaining how this special distribution of motion could have been set up originally, but at any rate it is the only distribution which could survive for any length of time. Since we find that the stars in the mean have the same motion as the cloud it follows that they also have the velocity corresponding to a circular orbit. This had been assumed by investigators of galactic rotation without much attempt at justification. By reference to the cloud we are now able to establish it firmly.

I think it is not going too far to say that the mere existence of the cosmic cloud is in itself a proof of galactic rotation. What has kept this gas distended through the galaxy instead of collapsing long ago into a dense nebula at the center? Some of the ways of evading collapse possible for particles with long free paths (the stars) are not open to a regular gas; so that the possible answers are very limited. The distension could be maintained by temperature; but the temperature of the cosmic gas (about 15,000°) is far too low. The only alternative is rapid rotation sufficient to counteract the pull of gravity. The very existence of the cosmic cloud, therefore, depends on rotation; and although there is not the same theoretical necessity for rotation of the galaxy of stars, the observed agreement of the motions shows that the latter also must be rotating.

The conception of the stellar system as a gas with stars for molecules, and its comparison with the genuine cosmical gas filling the same region and rotating in the same way, helps us to see more clearly the difficulty in the way of constructing a strictly permanent stellar system. With the cosmic cloud we have no difficulty in fulfilling the strict conditions of equilibrium, but that is because we neglect viscosity. Viscosity—the rubbing of one zone of gas on another zone rotating at a slightly different speed—must slowly change the distribution of rotation. Viscosity objects to the existing differential rotation, and tries to set up a condition of its own. But it can never succeed; it can only act as spoil-sport. As soon as it effects any serious change the density gradients already mentioned must be set up—which means that the cloud falls to the center of the system or departs into outer space. I daresay that in the end viscosity triumphantly establishes the law of motion it is striving for—only there is nothing left to obey it.

Similarly in the system of the stars we have a tug-of-war between the viscosity conditions and the simple pressure conditions which must inevitably end in the collapse or disruption of the system. The only question is how to arrange some kind of balance which will stave off this fate for a reasonable time. I have already referred to certain current solutions which seem to me to insist too strongly on the fulfilment of what we here identify as viscosity conditions, per-

haps not sufficiently recognizing that by the time these conditions prevail there will be no galaxy left.

Let us leave these deep waters of theoretical investigation, and for our last look at the galaxy use no other criticism than our common-sense. We have not much difficulty in imagining ourselves looking at it from outside, for the telescope reveals multitudes of spiral nebulae, seen from every aspect, any one of which, we believe, may be taken as a pattern of our own galaxy. Rotating? Obviously it is. It is just like a Catherine wheel. Permanent? It does not look very permanent. Every engineering instinct we possess protests that such disklike arrangements of matter are precarious, and their stability is not to be trusted. To emphasize our sense of the transitoriness of things, the other galaxies are rushing away at high speed as though our poor system were the plague-spot of the universe. In a few thousand million years our neighborhood will be nearly evacuated, and our skies will have lost one of their chief telescopic glories. This is a rough and ready way of treating serious problems, but it is not out of harmony with the results thrust upon us by stricter methods. Perhaps the lesson of the galaxies is to wake us from our dream of leisured evolution through billions of years. It is hard to credit our stellar system with so much age and endurance. It is more like a young man in a hurry.

STELLAR LABORATORIES[1]

By Theodore Dunham, Jr.

[With 1 plate]

A thousand years ago the stars were looked upon as fixed points of light permanently attached to the sky. A few brave minds dared to imagine them as more than this, but without accurate measuring instruments there could be only speculation as to the true nature of points of light. At present we look upon the stars as huge aggregations of matter, extremely hot and probably gaseous to the very center, held together by the mutual attraction of their separate particles and radiating away great quantities of light and heat. Where the ancients saw a single star, the increasing power of our telescopes has shown us more and more stars, until now we know many millions for each of theirs. One may perhaps ask why we are interested in knowing more exactly how the stars are built and what goes on below their surfaces.

In the first place there is our natural curiosity. The stars appear to be the parents of the planets, and so of all life in the universe. We ourselves are, in the last analysis, made up of minute particles which were once probably parts of a star—the sun. Millions of years ago the outer layers of the sun were as now, a swarm of atoms, so hot that no two could hold together long enough to build anything more organized than local eddy currents. We believe that suddenly another star, another great hot globe of gas, then swept by. It passed close enough to raise great tides in the sun and even to tear loose parts of the sun's outer layers. The passing star kept on, but the clouds of atoms, torn loose from the sun, had to face new conditions.

As they circulated in paths at various distances from the sun, they necessarily began to cool. As they cooled, their atoms began to hold together in groups of different kinds, and what had once been clouds of disorganized atoms torn from the sun slowly became

[1] Lecture delivered on Feb. 19, 1931, in Culbertson Hall, California Institute of Technology, Pasadena, under the auspices of the Astronomical Society of the Pacific and the Mount Wilson Observatory. Reprinted by permission from Publications of the Astronomical Society of the Pacific, vol. 43, No. 252, April, 1931.

definite bodies. On one of these bodies at least, we know that an organization of the atoms proceeded so far as to form not only land and water, but even that highest type of organization which we call life. And in the course of this mysterious process there finally emerged the brains of human beings, who have just recently begun to look back and to inquire into the makeup of the star from which they came.

It is an extremely interesting problem to try to explain with the help of physics and mathematics why a certain amount of material isolated in space should take on the particular size it does and begin to throw out in all directions energy at a particular rate. For everything we now know indicates that if you should put a certain number of million tons of cold stuff off in space it would do just that. If there were much more than this particular amount it would probably break up, and if there were much less it would never shine at all.

Another reason for making an intensive study of the stars is the hope that such a study may supplement physics as we know it in our terrestrial laboratories. The stars provide us with a wide variety of conditions. The temperatures at the surfaces of many far exceed any which we can as yet produce, while the pressures in their atmospheres are often lower than any which we can obtain in the laboratory. It is true that some things about the way atoms can behave have been learned first from the stars in recent years, but just now it seems more likely to be the other way about, and that physics, especially theoretical physics, will help to put together one of the most interesting puzzles known to us. And yet inside the stars is guarded the secret of at least one process which at present there is no prospect of duplicating in any terrestrial laboratory—the conversion of matter into energy.

If we could be allowed to ask 10 questions about any star and have them answered, I think they might be these:

1. What is its distance from us?
2. What is its velocity in space?
3. What is its true luminosity or candlepower?
4. How large is it, in miles?
5. What is its mass?
6. What substance is it made of?
7. What is the temperature at its surface and how does it change toward the center?
8. What is the pressure in its atmosphere and how does it change toward the center?
9. How long is the life of a star?
10. The most interesting question of all, What is the source of its continual flow of light and heat?

It is asking a great deal to expect to find out the detailed structure of an object which never appears otherwise than as a point of light, even in the largest telescope, but I hope to show that some of our questions about such an object can nevertheless be answered.

The distance of a star was first measured by the amount of change in its apparent direction when the observer was carried from one side of the earth's orbit to the other side six months later. Even before the distance of any star was known, astronomers had noticed that some stars had changed their positions over a period of years. Arcturus had moved rather more than 1 degree since the beginning of the Christian era. This might mean either that Arcturus was close to us and moved slowly, or that it was far away and traveled very fast. As soon as the distance became known, however, the apparent motion could at once be translated into true motion, and this turns out to be 84 miles per second. Most stars are found to be moving at a more deliberate pace, but 10 to 20 miles per second is very common among the stars.

It is easier to picture how far away a star like Arcturus must be, if we realize that even when moving at 84 miles a second it takes about 800 years for its direction to change by as much as the moon's apparent diameter.

Knowledge of the distance of a star at once unlocks another most important fact, namely, its true luminosity or candlepower. A star will look bright either if it is very close and of moderate brightness or if it is far away and extremely brilliant. If the distance can be measured, we can decide immediately between these two possibilities, and from the apparent brightness we can find the actual candlepower of the star.

It turns out that the candlepower of the stars varies to a remarkable degree. There is, in fact, as much difference between the faintest and the brightest as between a firefly and a powerful searchlight. Our sun holds a place half-way between these limits and would correspond to an ordinary household electric light.

In marked contrast to this great range in intrinsic brightness among the stars is their unexpected similarity in mass. It would be extremely difficult, and perhaps impossible, to determine the mass of a star were it not for the fortunate circumstance that many pairs of stars are known in which the two are held together by their mutual attraction while they revolve around a common center of gravity in elliptical orbits. If we know how far away such a pair of stars is from us, we can find out their masses from the speed with which they swing each other around in their orbits. The interesting result is that when we compare the masses of the stars with that of the sun we find them all very much alike. For there are a few

stars 10 times as massive as the sun, and nearly all have at least one-tenth its mass.

Now the true brightness of a star clearly depends on how big it is, but it also depends just as much on how bright a square inch of its surface is. And the brightness of each square inch is almost entirely a question of how hot it is. As a piece of iron is heated in a blacksmith's forge it gives out no visible light at first, but in time it begins to glow with a feeble reddish light. As the temperature increases two things happen. It gives out more light from each square inch, and the quality of the light changes from reddish to yellowish, and finally at very high temperatures is intensely bright and looks nearly white. These changes always happen together. It is impossible to heat a poker until it is very bright and to have it still look red. And it is equally impossible for a feebly shining poker to look white. Now the astronomer, imprisoned as he is upon the earth, far from his celestial experiment, is quick to take advantage of such a reliable connection between the surface brightness, the surface temperature, and the color of an object.

In order to find the temperature of a star it is only necessary to measure its color. This is a straightforward process if a prism is used to break up the colors. Then by means of a photographic plate, or, still better, a radiometer, thermocouple, or photoelectric cell, the relative strengths of the red and the blue are measured. The proportion of blue light to red light increases as the temperature rises, and if a star is found to have a certain proportion of blue to red light its temperature can easily be inferred. It is worth while to note that we have here a means of finding the temperature of a star without knowing anything at all about its distance. For the color of an object ordinarily depends in no way on whether it is close or far away.

As a matter of fact there are two exceptions to this rule. The setting sun looks red when the air is filled with smoke from a forest fire because the short waves of blue light are scattered by the tiny particles of smoke, while the longer red waves pass through to our eyes with little interference. The same thing may happen to starlight. It has been shown recently that some stars, particularly those at great distances, look redder than others, which in every other respect appear to be the same kind of star. This is taken as evidence for the existence of clouds of very small particles of material in the otherwise empty spaces between us and some of the distant stars. If such clouds of material are at all uniformly distributed through space, stars will look redder the farther away they are.

The only other known case in which the color of objects is influenced by their distance is that of the extremely distant nebulae,

but here the apparent reddening seems to be due to properties of space which reveal themselves when great intervals are involved. Neither of these effects needs to be considered in studying stars relatively close to us within our own system. And so we may quite confidently infer the temperatures of these stars from their colors.

We come now to the question, "How big are the stars?" Since we can not see the disk of any star with any telescope, we may proceed by an indirect method.

Suppose that I had a cannon ball and also a small bullet of something harder even than tungsten to melt. Suppose I were to place them side by side a quarter of a mile away where you could not see the disk on either, and heat them both equally until they were faintly red hot. The cannon ball would be quite easily visible, but the bullet would be so faint that you could hardly see it. If I assured you that they were equally distant and you could see that the color of both was the same you would at once know that the bullet must be smaller than the cannon ball, and if you had an instrument to measure how much fainter the bullet looked you could tell just how much smaller it must really be than the cannon ball.

But now suppose I should somehow heat the bullet to a much higher temperature, so that it looked brilliantly white hot and should adjust the temperature until the bullet gave out as much light as the much larger, dull red cannon ball. Again suppose that I assured you the two were equally far away. If you were color-blind you would merely see two equally bright points of light and might quite naturally suppose them to be of equal size. But if your eyes were normal eyes you would almost instinctively allow for the fact that the white-hot bullet must be far brighter for every unit of its surface than the cooler, redder cannon ball. You would know that if the two seemed equally bright the white-hot bullet must be the smaller.

In just the same way the astronomer who has measured the distance and the color of a star can calculate its diameter in miles. Within recent years these calculated diameters have been beautifully confirmed by direct measurement of the diameters of several of the larger stars with the interferometer, an instrument which makes it possible to measure the apparent diameter of a star too small and too distant to show a disk in a telescope.

With this confirmation of the method, the diameters of many stars have been determined. They show a remarkable range in size, from stars like the faint companion of Sirius, which is not much larger than the earth, all the way up to Antares, which is so tremendous a star that if the sun were at its center the orbit of the earth and even that of Mars would still be well below its surface.

Now the masses of the stars do not show anything like this wide variation. In fact, we can say in a general way that all stars are made of pretty nearly the same amount of matter. And if this is the case, then matter must be very tightly packed in the small stars and spread very thin in the larger stars. If we could dip up with a teacup a sample of the stuff of which the companion of Sirius is made, we should need a powerful derrick to lift it, for at the surface of the earth it would weigh about 10 tons. It is hard to see how matter can be so tightly packed as this. The other extreme is no easier to understand, for an ordinary room full of the average stuff of which Antares is built would weigh hardly more than an ounce and the outer parts of the star must have matter even more rarefied than in the best vacuum we can produce in our own laboratories. It is hard to understand how a star built of such thin stuff can be sufficiently opaque to show any definite shape at all, but modern physics has answers ready for both these questions.

The methods so far described have given us much information about the characteristics of many stars—their distances, sizes, masses, and superficial temperatures. But we are never satisfied. What we should really like to do is to be able to dip a thermometer into the stars and attach to them pressure gauges and read off their temperatures and pressures directly. We should also like to attach speedometers to stars to find out their velocities. Unfortunately we can not do this. But, as a matter of fact, nature has provided us with instruments which act as excellent thermometers, pressure gauges, and speedometers, if only we can read them. They occur in great numbers throughout the universe. They are atoms in the stars.

Now it is true that atoms do not carry indicating dials on which we can read off directly what we want to know about the stars; but although very small they are nevertheless remarkable mechanisms, extraordinarily sensitive to the conditions in which they find themselves. All the light which comes to us from a star has started from individual atoms, and so the light carries with it a record of the physical conditions under which it was sent out. The atoms in the stars have been broadcasting a description of their surroundings for millions of years, but it is only recently that we have paid the least attention. The spectroscope has made it possible to record these atomic messages, but they are always in code. The study of atoms in our laboratories is giving us the key to this code and is helping us to read the information which is hidden in a stellar spectrum.

We must not ask to see a correct and up-to-date picture of an atom. That has been impossible since 1925, in which year the atom became a ψ function in higher mathematics and quite impossible to draw. It is just as real as it ever was, however, and just as reliable. But for

our purposes it will be entirely satisfactory to think of the simpler and older model with electrons revolving around a central nucleus.

To make things simpler still, we shall consider only one kind of atom, the calcium atom, because it illustrates so well some of the things I wish to describe. A calcium atom on the model we are using consists of a central positive nucleus which holds by electrostatic attraction 20 negative electrons. Eighteen of these revolve about the nucleus in orbits relatively close to the nucleus and do not take any part in giving out the light which we see coming from the stars.

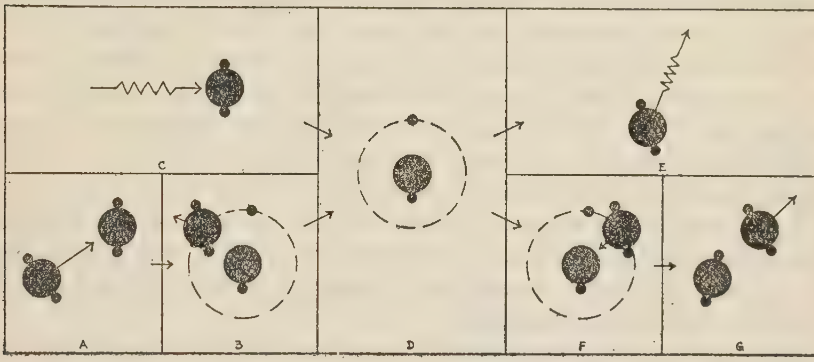

FIGURE 1.—Atomic transformations

A, a rapidly moving atom colliding with a normal atom. *B*, after the collision the first atom recedes more slowly than it approached, having transferred part of its energy to the second atom which is now in an excited state, i. e., one of its electrons now occupies a larger orbit. *C*, a light dart colliding with a normal atom able to absorb the exact amount of energy carried by the light dart. *D*, an excited atom which has stored the energy resulting from a collision either with another atom or with a light dart. *E*, the electron which occupied an excited orbit has fallen back to its normal position, and the energy which it had stored at *D* now appears in the form of a light dart traveling in a random direction. *F*, a slowly moving atom colliding with an excited atom. *G*, after the collision, the first atom is recoiling more rapidly than it approached, having taken up energy from the excited atom which is left in its normal state. An atom may become excited in two ways and an excited atom may unload its energy in two ways. Accordingly, atomic transformations may follow any one of four cycles;

A→B→D→F→G
A→B→D→E
C→D→E
C→D→F→G

In Figure 1 the nucleus and these 18 inner electrons are all represented by a large dot. But the two outer electrons are very important. These are shown as smaller dots.

Normally these two outer electrons circulate close to the nucleus. But they may also circulate in a number of larger orbits, of definite sizes. Intermediate positions do not occur. Now it takes energy or work to lift an electron from a smaller orbit to one of these larger or "excited" orbits, and this lifting of the electron can be done in either of the two ways illustrated in Figure 1. The first is by a

collision with another atom. The atom is rushing about at the rate of 2 or 3 miles a second among other atoms in a star and frequently collides with its neighbors. The violence of one of these collisions may be just enough to raise the electron to a larger orbit.

The second way in which an electron can be raised to a higher orbit is by a collision with a dart of light. In the atmosphere of a star great quantities of light are coming through from deep layers on their way to the surface. As far as the atom is concerned this light acts as if it were in the form of minute darts of energy, each with a very definite rate of vibration and carrying a definite amount of energy. Those vibrating rapidly have short wave lengths, carry a large amount of energy, and appear blue to our eyes. Those vibrating more slowly have longer wave lengths, carry less energy, and appear red. One of these light darts may strike an atom in its path, and, if the atom can respond exactly to the rate of vibration of the light dart, the energy which the light dart carries may raise one of the electrons in the atom to a larger orbit farther from the nucleus. Since the light dart is made of nothing but energy, and since it has transferred all of this energy to the atom, it entirely disappears as the result of striking the atom.

Whether the atom was struck by another atom or whether it was hit by a light dart, the result is the same, namely, an atom that is wound up and has stored within it a definite amount of energy—the power to do work of some kind. But this lasts only for an instant. The electron must fall back. If undisturbed, the excited atom hesitates for about a hundredth of a millionth of a second, and then the electron falls to its normal place again. In doing so it unloads the energy it borrowed by shooting off another light dart exactly like the one which was absorbed. The only difference is that since the atom has absolutely no idea of aiming, the light dart is sent out entirely at random.

There is another way in which the electron can fall back. While the atom is wound up and hesitating, another atom may strike it while traveling at a relatively moderate speed. If this happens the atom may unload its stored energy directly to this second atom. The colliding atom then bounces away faster than it struck, just as if it had touched off a stick of dynamite, while the electron in the first atom settles back into its normal orbit.

We may now ask how atoms capable of passing through cycles such as we have described are able to write code messages in stellar spectra from which we may infer the conditions existing in the outer parts of stars. To understand this we must first consider what happens when in the laboratory we artificially stir up an atom to produce a spectral line. This may be done quite easily by means of an electric

arc in which many atoms collide so hard with one another that their electrons are forced into excited orbits from which they fall back with the emission of light darts.

If a light dart is thrown out by an atom whose electron has fallen a long distance, i. e., from a very large orbit to a small one, then the light dart must carry away a large amount of energy, and it does this by vibrating at high frequency. But if it was thrown out by an atom which had less energy to unload because its electron did not have so far to fall, then the light dart will vibrate more slowly. Since both darts travel at the same speed, the high-energy

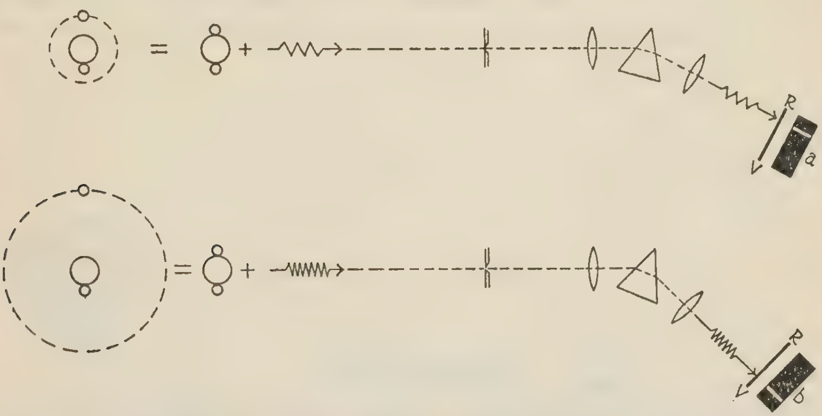

FIGURE 2.—The formation of bright spectral lines

Two atoms are shown, each with an electron in an excited orbit. Such atoms have in store an amount of energy which depends on the size of the orbit which the electron occupies. When the electron returns spontaneously to its normal orbit, the stored energy is thrown out in the form of a light dart. An electron falling from a relatively small orbit emits a small amount of energy. The resulting light dart has a low frequency of vibration, a long wave length, and appears at the red end of the spectrum. An electron falling from a larger orbit emits more energy, and the corresponding light dart has a higher frequency, a shorter wave length, and appears in the violet region of the spectrum. The light darts affect the photographic plate where they strike. At *a* and *b* the plates are turned through a right angle to show the resulting spectral lines.

dart will have a short wave length, while the low-energy dart will have a long wave length. Figure 2 shows two such light darts approaching the slits of two spectrographs.

The prism bends a high-energy light dart more than a low-energy dart, and the two will strike a photographic plate at entirely different places. Thus by measuring the image on the photograph we have an absolutely direct method of knowing how big a jump the electron made in the atom.

There are all conceivable kinds of jumps between the many possible orbits in which the electrons may start and end, but each sends out a slightly different light dart, which, after passing through the

prism of our spectrograph, ends up in a different place on the photograph.

Now to go back to the star. The hot, deep parts of the star are sending out light darts of every conceivable wave length. Except for a few which are stopped in the atmosphere of the star these light darts leave the star, and after traveling for years through empty space a small part of them strike the earth, and a still smaller part fall upon the lens or mirror of one of our telescopes, and are collected together and sent through a spectrograph (fig. 3).

The spectrograph will sort these darts out according to their wave length, sending the short, blue ones to one end of the photographic plate, the longer, green ones to the middle, and the still longer, red

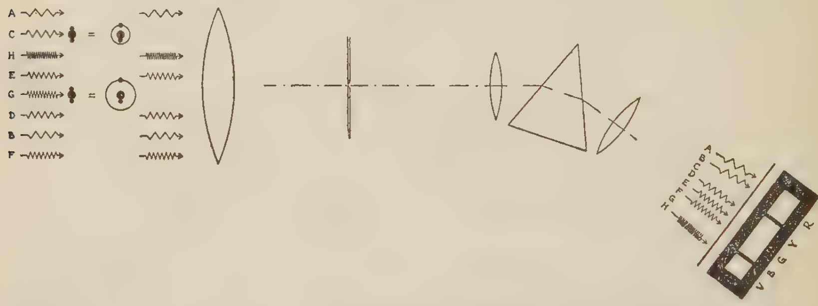

FIGURE 3.—The formation of a continuous spectrum with dark absorption lines

Light darts of every conceivable wave length and frequency of vibration are emitted by the hot interiors of stars. If these could pass to the earth unobstructed, our spectrograph would sort them into a continuous band on the photographic plate, the light darts of longer wave length (red light) going to one end of the plate and those of shorter wave length (violet light) going to the other end. The two atoms shown in the diagram are supposed to be in the atmosphere of a star and to be capable of becoming excited through the absorption of quantities of energy exactly corresponding to the quantities carried by the light darts *C* and *G*. As a result, these particular light darts are absorbed in the stellar atmosphere and are missing from the otherwise continuous band of color which falls upon the plate. The spectrum shows a bright background crossed by two absorption lines.

ones to the other end of the plate. Since the deep layers of the star are giving out light darts of every possible wave length, after passing through the prism, there will be a solid band of color. We call this a continuous spectrum.

But the interesting thing is that some of these light darts do not escape from the star. Some of them of particular wave lengths are sidetracked by atoms which absorb them in the outer layers of the star, and never get to the earth at all. Where they would have fallen on the plate there are dark empty spaces. This is how we first discovered that there are atoms in the stars. These dark spaces on the plate we know as spectral lines and they make up our code message from the stars.

We are now ready to look at the actual situation in a stellar atmosphere. Figure 4 represents a thin slice through the middle of the atmospheres of three different stars. The center one represents the atmosphere of our sun. Light and heat are coming up in great amounts from the depths of the sun below the bottom of the diagram.

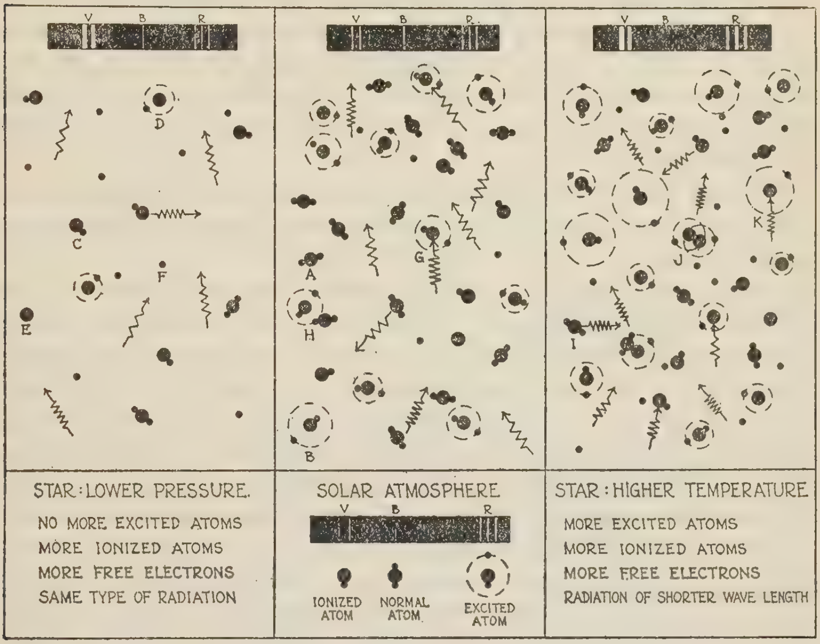

FIGURE 4.—Atomic processes in stellar atmospheres

The diagram shows idealized cross sections of three stellar atmospheres to illustrate the influence of temperature and pressure on the relative numbers of normal, excited, and ionized calcium atoms and the resulting differences in the spectra of the light which has come to us after passing through these atmospheres. The spectrum at the lower part of the diagram shows the lines characteristic of each of the three types of calcium atoms. Differences in the relative intensities of these lines in the spectra of various stars serve as measures of the numbers of atoms of each type which are present in the atmospheres of these stars, and so make it possible to infer the temperatures and pressures at the surfaces of the stars. The spectra in this diagram are in the form of photographic negatives so that dark absorption lines appear as white lines on a dark background. *A*, a normal atom; *B*, an excited atom; *C*, an ionized atom; *D*, an excited atom; *E*, a doubly ionized atom, which has lost two electrons; *F*, a free electron; *G*, a light dart colliding with a normal atom and exciting one of its electrons; *H*, two atoms which have just collided; one of them is left excited; *I*, an excited atom which has returned to its normal condition, emitting a light dart in a random direction; *J*, an excited ionized atom which is exciting another ionized atom by collision; *K*, a light dart exciting an ionized atom.

After working their way between the atoms in the atmosphere they pass on beyond the top of the diagram, through the upper limits of the atmosphere, and plunge off into outer space.

At the high temperature of the solar atmosphere, all the atoms are moving about quite rapidly and colliding frequently with one an-

other, so that if at any one instant a snapshot photograph, such as this diagram, could be taken, we should find that a considerable number of the calcium atoms had just undergone collisions which had lifted one of their electrons into a larger or excited orbit.

At this temperature light darts are also very plentiful, rushing about in all directions among the atoms. By striking normal atoms, they produce still more excited atoms. When an atom which has already been excited by one collision is struck a second time before it has recovered from the first collision, the electron may be knocked entirely off the atom. The mutilated atom which remains is called an "ionized" atom.

We have, then, in the solar atmosphere at any one instant three kinds of calcium atoms: The normal atom, the excited atom, and the ionized atom.

Now, we have seen that any particular atom can absorb a light dart if the energy of the light dart is of exactly the right amount to raise one of the electrons in the atom into one of its possible orbits. If this happens, that particular light dart is lost forever as far as we and our spectrographs are concerned, because the atom, in unwinding, will either send out a second dart in a random direction or else will use the stored energy to kick one of its neighbors, in which case the energy goes into heat and is again diverted.

Thus the atoms in the atmosphere stand at the gateway between the star and outer space and each one sidetracks light darts of a particular energy and color. The result is that each type of atom is responsible for characteristic gaps or dark lines in the otherwise continuous band of color.

The normal calcium atoms absorb blue light, causing a single dark line in the blue part of the spectrum. The excited atoms absorb red light, causing primarily a strong group of three lines close together in the red part of the spectrum, while the ionized atoms which have lost an electron absorb violet light, causing a pair of conspicuous lines in the violet.

Now, the strength of these spectral lines depends in a striking way on the number of atoms causing them, so that if with our spectrographs we can measure the strength of the lines it means that we can count the number of atoms of each kind. When many atoms cause a line, the line is wide and when the atoms are few the line is narrow. This we speak of as differences in line-intensity.

In the sun the lines we are discussing are of very different intensities, but they have intentionally been made equal in Figure 4 so as to bring out more clearly the variations when we pass to other stars.

In the right-hand section of the diagram we have the atmosphere of a star, such as Procyon, which is at a higher temperature

than that of the sun. The atoms are rushing about more rapidly, and on the average the light darts are more numerous and also more energetic. The vibrations are faster and the wave lengths are shorter. Because the light darts are more energetic and because the collisions are more violent at this higher temperature there will be fewer normal atoms. More atoms will be excited and more will be ionized than in the sun. Now, as we have seen, the width and the strength of a spectral line depends on the number of atoms responsible for it. A single atom would never show a line in our spectrograph, but when several million million are doing the same thing at once enough light is held back to make a noticeable dark line. In the present case the line in the blue corresponding to the normal atom is weaker than in the sun, while the triplet in the red, corresponding to the excited atoms is considerably strengthened, and so is the pair of lines in the violet corresponding to the ionized atoms. What we can observe is of course only the spectrum and not the atoms responsible for it. So when we see a spectrum whose lines have these relative intensities we must infer that we are dealing with a star that is hotter than the sun.

The left part of the diagram represents the atmosphere of a very different kind of star such as γ Cygni. The temperature here is the same as in the sun, but the pressure is much lower. Since the temperature is the same, the violence of the collisions is the same, the number and energy of the light darts is the same, but the pressure is lower, which means that the atoms are farther apart. Occasional atoms will become ionized, just as in the case of the sun, because collisions with light darts will be no less effective. But when once an electron has been torn loose from an atom it will be much more difficult for this free electron to find another mutilated atom with which it can recombine to form a normal atom. And so it happens that in this star the proportion of ionized atoms is greater than in the sun, while the number of normal and excited atoms are both reduced, without changing their proportion relative to one another.

The increased number of ionized atoms results in a marked strengthening of the pair of lines in the violet. The line in the blue corresponding to the normal atom and the red triplet corresponding to the excited atom are somewhat weaker than in the sun, but the relative strengths of these lines remain unchanged.

The net result of all this is that, when we develop a photographic plate taken with our telescope and find on it a spectrum with the red triplet looking stronger than the blue line, we know that the light must have come from a star with an atmosphere at a high temperature, while if we get a spectrum with the violet pair stronger than the blue line, we know that we are dealing with a star whose

atmosphere is at low pressure. When we combine this method with what can be learned from the colors of the stars we find temperatures ranging all the way from 1,600° in long-period variable stars at minimum brightness up to over 30,000° C. for the hottest blue stars.

The pressures in the atmospheres turn out to be surprisingly low, and, although there are wide variations from star to star, the pressures do not in general exceed one-thousandth of that of air at the earth's surface. On some stars the atmospheres are at pressures much lower than this. The entire atmosphere of the sun as far down as we can see is about 50 to 100 miles deep, but there is so little stuff in all this depth that it corresponds to only about 5 or 6 feet of ordinary air. An amount of material which is absolutely transparent here becomes so foggy on the sun as to be nearly opaque, because of the great number of free electrons and ionized atoms which can stop passing light darts and send them flying off in other directions and even turn them into heat.

I have said that there are great differences in the pressures at the surfaces of different stars. Differences in pressure must mean differences in the force with which gravity packs down the material. And differences in the force of gravity must mean one of two things: Either differences in the masses of the stars or differences in the distance from the surface to the center. We have already found that the masses of all the stars are more or less alike, but that their sizes do differ enormously. And so the pressure differences which we can interpret from the line-intensities in the spectra of these stars really mean differences in the sizes and therefore in the actual brightness of the stars. Of course, we want to know the true candlepower of as many stars as possible, in order that we may determine their distances, which, as we have seen, may be done with the aid of their apparent brightness.

If we could really count accurately the number of calcium atoms of the three kinds shown in Figure 4 by measuring the strengths of the spectral lines which they produce, and if the simple theory connecting the numbers of the three kinds of atoms with the temperature and pressure were entirely satisfactory, we could, by studying the spectrum of a star, calculate exactly what pressure must exist in its atmosphere to give this spectrum and could go from that to its true brightness. Some day we hope that it may be possible to do this, but at present the results can be only approximate because the conditions in stellar atmospheres are more complex than Figure 4 indicates.

Fortunately a powerful empirical method can be used. In 1914 Doctor Adams and Doctor Kohlschütter studied in detail the differences in the spectra of nearby stars whose true brightness was already known. We have seen that the spectra of two stars may be very

different, even when the temperature of the two is the same, the difference being due entirely to pressure, which means that the difference is connected with the sizes, and so with the luminosities of the stars.

When enough stars of known brightness had been studied to show just how the spectrum depends on intrinsic brightness, it was quite simple to match with these the spectra of other stars and thus find their true brightness and from that their distance. It is the distance which we particularly want for mapping out the arrangement of the stars in space, and this method for deriving it looked at first too good to be true.

But the severest tests have only increased our confidence in its reliability. The distances of several thousand stars have been determined in this way, including many much too far away to investigate by the direct surveying method. We must not forget, however, that the calibration of this far-reaching spectroscopic method depends entirely on the surveyed distances of representative stars.

So much for temperature and pressure revealed to us by the atoms. They tell us three other things. First, the velocity of a star toward us or away from us. The positions of the lines in the spectrum of a stationary star are well known and can be depended upon not to vary by one part in a million. But if the star is moving toward us at any considerable speed the waves of light tend to pile up slightly, and more of them enter our spectrograph in a second than would if the star were at rest. This results in displacing all the spectral lines to the violet of their normal positions, and the amount of the displacement is a measure of the velocity of the star. This method is not adapted to measuring the velocity of a man walking down the street; in fact it could just detect the motion of a racing car headed toward the telescope and carrying a neon lamp as a source of light. But it is well adapted to measuring stellar velocities, which are often 20 or 30 miles a second.

When a star rotates and the axis of rotation does not happen to point directly toward us, one side of the star will approach us while the other recedes. The approaching side of the star tends to displace all spectral lines to the blue, while the other side displaces these same lines to the red. The result is that the lines are greatly widened and no longer look sharp. Plate I (A) and (B) shows the spectrum of α Aquilae, a rapidly rotating star, with the spectrum of α Cygni for comparison. The distinguishing feature of the spectrum of a rotating star is that all the lines are widened.

It has long been known that if an atom emits light while in a strong electric field some of the lines are widened. In some of the hotter stars, the hydrogen lines are extremely wide, while the metal-

lic lines are still relatively sharp. Since hydrogen shows the effect of an electric field far more than any other element, it is believed that such fields are present in these hot stars. Plate 1 (*C*) and (*D*) shows the spectra of Sirius with α Cygni again for comparison. It is easy to see that each member of the series of hydrogen lines in Sirius is considerably wider than in α Cygni. Spectra on a larger scale show little difference in the metallic lines. Electric fields in a stellar atmosphere are probably caused chiefly by the negatively charged electrons and the positively charged ions passing close to the atoms and disturbing them. The number of charged particles close enough to disturb an atom naturally increases with the pressure, and so it begins to look as if the widths of spectral lines, particularly of the hydrogen lines, may in the future serve as another indicator of the pressure.

In everything thus far said we have considered the atmosphere of the star as a whole, since we can not see its disk; and the atoms have shown themselves only by absorbing out light from the continuous spectrum of the white light which passes by them from the inside of the star. In one case only can we study the atmosphere of a star without interference from the light inside and that is our own star, the sun, when the moon passes across it at the time of a total eclipse. For several seconds the main body of the sun is then entirely covered, while the atmosphere at its edge still shows. A spectrogram made at such a time shows a spectrum of the atmosphere entirely by itself, and the atoms of the vaporized metals above the sun give their own pure spectrum of bright lines. Plate I (*E*, *F*, *G*) shows such a spectrum taken at the eclipse in northern California on April 28, 1930. The light of the disappearing crescent of the solar atmosphere is split up into more than a thousand separate crescents of different colors. Each of these crescents shows by its intensity the amount of the element to which it belongs in the solar atmosphere. The bright bands of continuous spectrum were caused by minute bits of the sun itself, which still showed through deep valleys on the edge of the moon when the photograph was made. The intervening mountains projected beyond the solar disk, and there we obtained a spectrum of the upper atmosphere without any of the lower strata.

Another way to take a spectrum of the solar atmosphere at an eclipse is to use a spectrograph with a slit and to move the plate by means of a screw at an even rate of speed while the moon is covering the sun's atmosphere. One of the best plates of this kind was taken by Doctor Campbell, of the Lick Observatory, at the eclipse of 1905. The moon moves in its orbit about half a mile in every second, which means that it covers up about 200 miles of solar

atmosphere each second. This gives us a scale of miles on the plate, and we can see just how the solar atmosphere fades away in its upper regions. It turns out that most of the ordinary absorption spectrum is given by a layer not much more than 100 miles thick. But above this is a vast outer atmosphere known as the chromosphere in which the various elements reach up to different heights. Calcium and hydrogen have been traced as high as 10,000 miles. It is probable that it is the pressure of the intense light from the solar surface below which supports these atoms, since the gas pressure at this level would be entirely inadequate. A study of the chromosphere is particularly interesting because it is one of the few places in the universe where atoms can be examined while acting each one for itself, without disturbance by its neighbors. The pressure is in fact so very low that an atom probably travels thousands of miles without striking another atom, whereas the particles of air under ordinary conditions are experiencing thousands of collisions in every inch they move.

So far I have said nothing about the insides of stars. We have been discussing only the merest outer skin, which is kept in its present brilliant state by what is going on below. When we inquire into the conditions within a star, the methods which are useful for determining temperatures and pressures at the surface fail us and we are thrown back on what Eddington calls an "analytical boring machine." If we give the problem to a mathematician, telling him that he may assume the material to act as a perfect gas and ask him to apply the elementary principles of physics, he will come back with a large part of the answer.

It turns out that the temperature at the center of the sun is about 30,000,000° C., that the pressure is 200 million tons on every square inch of area, and that the material is crowded until it has 28 times the density of water. Under these conditions the atoms are scarcely recognizable. They have had all but their last few electrons torn away, and are rushing about with velocities which would carry them from California to New York and back in a second if their directions were not changed a million times in the interval.

All this is interesting enough, but there is one thing still more remarkable about the stars. They are sending into outer space tremendous quantities of heat and light, and they have been doing it for a long time in the past. Geologists tell us that the earth must have been here for at least a thousand million years. But there are various astronomical arguments which lead us to believe that the stars have ages even a thousand times as great as this.

No source of energy with which we are familiar could provide so much heat for so long a time. Simple cooling would last only a short

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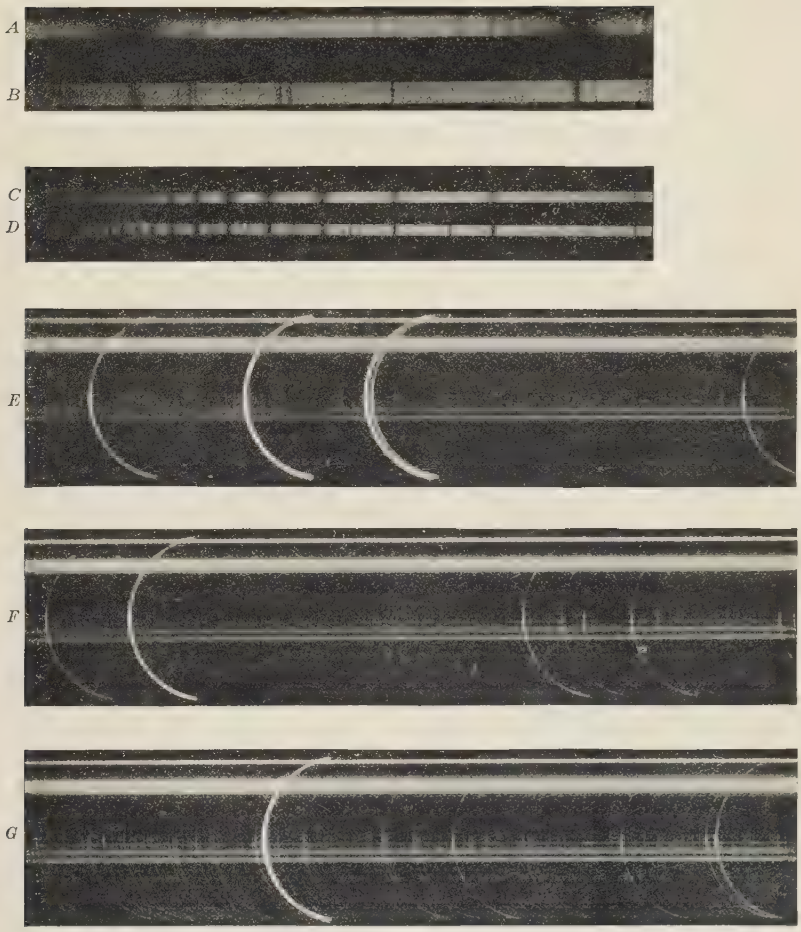
time. The burning of hydrogen and oxygen would not last the sun more than one-tenth of the lifetime of our earth. Radium has been suggested. If the sun were made of pure radium, it would give out as much heat as the sun has given out since the earth was started, but it would be very unequally distributed over this period of time. For 2,000 years the sun would shine with a furious heat and then rapidly cool and become invisible.

Only two possibilities remain. The first is that matter itself is being transformed into radiant energy deep in the stars. If this is the source of the sun's heat, we can calculate on the theory of relativity that the sun is consuming every three hours as much matter as there is in the bulk of Mount Wilson. And yet the sun is so large that it could well stand this loss and go on shining for several million million years to come.

The other possibility is that the stars were once composed entirely of hydrogen and that the atoms of hydrogen are uniting to build up the heavier atoms of other elements. In the process of becoming thus tightly packed, a small but definite fraction of the mass must be lost, and its equivalent must appear as energy. If this is the source of stellar energy, the life of a star is 100 times shorter than if there were complete annihilation of matter, and every two minutes a mass of hydrogen equivalent to the bulk of Mount Wilson is built up in the sun into atoms of more complex elements.



A, *α Aquilae*. Rapid rotation. All lines widened; *B*, *α Cygni*. No noticeable rotation. Lines not widened; *C*, *Sirius*. Moderate pressure in the atmosphere. Hydrogen lines widened by electric fields. Metallic lines relatively narrow; *D*, *α Cygni*. Very low pressure in the atmosphere. Hydrogen lines relatively narrow; *E*, *F*, *G*, Flash spectrum of the solar atmosphere photographed at Honey Lake, Calif., April 28, 1930. *E*, a region in the violet. The left member of the close pair of crescents is due to ionized calcium (H), while the right member is due to hydrogen ($H\epsilon$). The two strong crescents at the left of *F* are due to ionized strontium ($\lambda 4077$) and hydrogen ($H\delta$). *G* shows the strong $H\gamma$ crescent of hydrogen in the blue with many weaker crescents caused by atoms of iron, titanium, and other metals

PRESENT STATUS OF THEORY AND EXPERIMENT AS TO ATOMIC DISINTEGRATION AND ATOMIC SYNTHESIS [1]

By Robert A. Millikan

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My task is to attempt to trace the history of the development of scientific evidence bearing on the question of the origin and destiny of the physical elements. I shall list 10 discoveries or developments, all made within the past 100 years, which touch in one way or another upon this problem and constitute indications or sign-posts on the road toward an answer.

Prior to the middle of the nineteenth century little experimental evidence of any sort had appeared, so that the problem was wholly in the hands of the philosopher and the theologian. Then came, first, the discovery of the equivalence of heat and work, and the consequent formulation of the principle of the conservation of energy, probably the most far-reaching physical principle ever developed.

Following this, and directly dependent upon it, came, second, the discovery, or formulation, of the second law of thermodynamics, which was first interpreted, and is still interpreted by some, as necessitating the ultimate " heat-death " of the universe and the final extinction of activity of all sorts; for all hot bodies are observed to be radiating away their heat, and this heat after having been so radiated away into space apparently can not be reclaimed by man. This is classically and simply stated in the humpty-dumpty rhyme. As a natural if not necessary corollary to this was put forward by some, in entire accord with the demands of medieval theology, a Deus ex machina initially to wind up or start off this running-down universe.

Then came, third, the discovery, through studies both in geology and biology, of the facts of evolution—facts which showed that, so far as the biological field is concerned, the process of creation, or upbuilding from lower to higher forms, has been continuously

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[1] Retiring presidential address to the American Association for the Advancement of Science, delivered at Cleveland on Dec. 29, 1930. Reprinted, with author's revision, by permission from Nature, vol. 127, No. 3196, Jan. 31, 1931.

going on for millions upon millions of years and is presumably going on now. This tended to direct attention away from the Deus ex machina, to identify the Creator with His universe, to strengthen the theological doctrine of immanence, which represents substantially the philosophic position of Leonardo da Vinci, Galileo, Newton, Francis Bacon, and most of the great minds of history down to Einstein.

Neither evolution nor evolutionists have in general been atheistic—Darwin least of all—but their influence has undoubtedly been to raise doubts about the legitimacy of the dogma of the Deus ex machina and of the correlative one of the heat-death. This last dogma rests squarely on the assumption that we, infinitesimal mites on a speck of a world, know all about how the universe behaves in all its parts, or more specifically, that the radiation laws which seem to us to hold here can not possibly have any exceptions anywhere, even though that is precisely the sort of sweeping generalization that has led us physicists into error half a dozen times during the past 30 years, and also though we know quite well that conditions prevail outside our planet which we can not here duplicate or even approach. Therefore the heat-death dogma has always been treated with reserve by the most thoughful of scientific workers. No more crisp or more cogent statement of what seems to me to be the correct position of science in this regard has come to my attention than is found in the following recent utterance of Gilbert N. Lewis, namely, "Thermodynamics gives no support to the assumption that the universe is running down. *Gain of entropy always means loss of information and nothing more.*"

The fourth discovery bearing on our theme was the discovery that the dogma of the immutable elements was definitely wrong. By the year 1900 the element radium had been isolated and the mean lifetime of its atoms found to be about 2,000 years. This meant definitely that the radium atoms that are here now have been formed within about that time; and a year or two later the element helium was definitely observed to be growing out of radium here and now. This raised insistently the question as to whether the creation, or at least the formation, of all the elements out of something else may not be a continuous process—stupendous change in viewpoint the discovery of radioactivity brought about, and a wholesome lesson of modesty it taught to the physicist. But a couple of years later, uranium and thorium, the heaviest known elements, were definitely caught in the act of begetting radium, and all the allied chain of disintegration products. Since, however, the lifetime of the parent atom, uranium, has now been found to be a billion years or so, we

have apparently ceased to inquire whence it comes. We are disposed to assume, however, that it is not now being formed on earth. Indeed, we have good reason to believe that the whole radioactive process is confined to a very few, very heavy elements which are now giving up the energy which was once stored up in them—we know not how—so that radioactivity, though it seemed at first to be pointing away from the heat-death, has not at all, in the end, done so. Indeed, it seems to be merely one mechanism by which stored-up energy is being frittered away into apparently unreclaimable radiant heat—another case of humpty-dumpty.

The fifth significant discovery was the enormous lifetime of the earth—partly through radioactivity itself, which assigns at least a billion and a half years—and the still greater lifetime of the sun and stars—thousands of times longer than the periods through which they could possibly exist as suns if they were simply hot bodies cooling off. This meant that new and heretofore unknown sources of heat energy had to be found to keep the stars pouring out such enormous quantities of radiation for such ages upon ages.

The sixth discovery, and in many ways the most important of all, was the development of evidence for the interconvertibility of mass and energy. This came about in three ways. In 1901, Kaufman showed experimentally that the mass of an electron could be increased by increasing sufficiently its velocity; that is, energy could be definitely converted into mass. About the same time the pressure of radiation was experimentally established by Nichols and Hull at Dartmouth College, New Hampshire, and Lebedew, at Moscow. This meant that radiation possesses the only distinguishing property of mass, the property by which we define it, namely, inertia. The fundamental distinction between radiation and matter thus disappeared. These were direct, experimental discoveries. Next, in 1905, Einstein developed the interconvertibility of mass and energy as a necessary consequence of the special theory of relativity. If, then, the mass of the sun could in any way be converted into radiant heat, there would be an abundant source of energy to keep the sun going so long as necessary, and all our difficulties about the lifetimes of the sun and stars would have disappeared. But what could be the mechanism of this transformation?

Then came the seventh discovery, which constituted a very clear finger-post, pointing to the possibility of the existence of an integrating or building-up process among the physical elements, as well as in biological forms, in the discovery that the elements are all definitely built up out of hydrogen; for they—the 92 different atoms—were all found, beginning about 1913, by the new method of so-called positive ray analysis, to be exact multiples of the weight of hydrogen

within very small limits of uncertainty. This fact alone raises very insistently the query as to whether they are not being built up somewhere out of hydrogen now. They certainly were once so put together, and some of them, the radioactive ones, are now actually caught in the act of splitting up. Is it not highly probable, so would say any observer, that the inverse process is going on somewhere, especially since the process would involve no violation either of the energy principle or of the second law of thermodynamics; for hydrogen, the element out of which they all must be built, has not a weight exactly one in terms of the other 92, but about 1 per cent more than one, so that since mass or weight had been found in the sixth discovery to be expressible in terms of energy, the union of any number of hydrogen atoms into any heavier element, meant that 1 per cent of the total available potential energy had disappeared and was therefore available for appearance as heat.

When, about 1914–15 this fact was fitted by MacMillan, Harkins, and others into the demand made above in the fifth discovery for a new source of energy to keep the sun pouring out heat so copiously for such great lengths of time, it seemed to the whole world of physics that the building up of the heavier elements out of hydrogen under the conditions existing within the sun and stars had been practically definitely proved to be taking place. This would not provide an escape from the heat-death, but it would enormously postpone it, that is, until all the hydrogen in the universe had been converted into the heavier elements.

By this process, however, the suns could stoke at most but 1 per cent of their total mass, assuming they were wholly hydrogen to begin with, into their furnaces, and 99 per cent of the mass of the universe would remain as cold, dead ash when the fires were all gone out and the heat-death had come. But about 1917 the astronomer began to chafe under the time limitation thus imposed upon him, and this introduced the eighth consideration bearing upon our theme. He could get a hundred times more time—from now on, much more than that, because only a small fraction of the matter in the universe is presumably now hydrogen—by assuming that, in the interior of heavy atoms, occasionally a negative electron gets tired of life at the pace it has to be lived in the electron world, and decides to end it all and commit suicide; but, being paired by Nature in electron-fate with a positive, he has to arrange a suicide pact with his mate, and so the two jump into each other's arms in the nucleus, and the two complementary electron lives are snuffed out at once; but not without the letting loose of a terrific death-yell, for the total mass of the two must be transformed into a powerful ether pulse which, by being absorbed in the surrounding matter, is supposed to keep up

the mad, hot pace in the interiors of the suns. This discovery, or suggestion, to account for the huge estimated stellar lifetimes, of the complete annihilation of positive and negative electrons within the nucleus, makes it unnecessary to assume, at least for stellar lifetime purposes, the building up of the heavier elements out of hydrogen. Indeed, it seems rather unlikely that both kinds of processes, atom-building and atom-annihilating, are going on together in the same spot under the same conditions; so we must turn to further experimental facts to get more light.

The ninth sign-post came into sight in 1927, when Aston made a most precise series of measurements on the relative masses of the atoms, which made it possible to subject to a new test the Einstein formula for the relation between mass and energy, namely, $E=Mc^2$. This Aston curve is one of the most illuminating finger-pointings we now have. It shows that:

1. Einstein's equation actually stands the quantitative test for radioactive or disintegrating processes right well, and therefore receives new experimental credentials.

2. The radioactive or disintegrating process with the emission of an alpha ray must be confined to a very few heavy elements, since these are the only ones so situated on the curve that mass can disappear, and hence heat energy appear, through such disintegration.

3. All the most common elements, except hydrogen, are already in their most stable condition; that is, their condition of minimum mass, so that if we disintegrate them we shall have to do work upon them, rather than get energy out of them.

4. Therefore, man's only possible source of energy other than the sun is the upbuilding of the common elements out of hydrogen or helium, or else the entire annihilation of positive and negative electrons; and there is no likelihood that either of these processes is a possibility on earth.

5. If the foregoing upbuilding process is going on anywhere, the least penetrating and the most abundant radiation produced by it, that corresponding to the formation of helium out of hydrogen, ought to be about 10 times as energetic as the hardest gamma rays, that is, it ought to correspond to about twenty-seven million electron-volts in place of two and a half million.

6. Other radiations corresponding to the only other abundant elements, namely, oxygen (oxygen, nitrogen, carbon), silicon (magnesium, aluminum, silicon), and iron (iron group), should be found

about 4 times, 7 times, and 14 times as energetic as the "helium rays."

7. The radiation corresponding to the smallest annihilation process that can take place—the suicide of a positive and negative electron—is 350 times as energetic as the hardest gamma ray, or 35 times as energetic as the "helium ray."

This brings us to the tenth discovery, that of the cosmic rays. These reveal:[2]

1. A radiation, the chief component of which, according to our direct comparison, is five times as penetrating as the hardest gamma ray, which, with the best extrapolation we can make on the curve connecting energy and penetrating power, means a ray 10 times as energetic as the hardest gamma ray, precisely according to prediction.

2. Special bands of cosmic radiation that are roughly where they should be to be due to the formation of the foregoing abundant elements out of hydrogen, though (for reasons to be given presently) no precise quantitative check is to be expected except in the case of the helium rays.

3. No radiation of significant amount anywhere near where it is to be expected from the annihilation hypothesis, thus indicating that at least 95 per cent of the observed cosmic rays are due to some other less energetic processes.

4. A radiation that is completely independent of the sun, the great hot mass just off our bows, and not appreciably dependent on the Milky Way or the nearest spiral nebula, Andromeda, one that comes in to us practically uniformly from all portions of the celestial dome, and is so invariable with both time and latitude at a given elevation that the observed small fluctuations at a given station reflect with much fidelity merely the changes in the thickness of the absorbing air blanket through which the rays have had to pass to get to the observer.

This last property is the most amazing and the most significant property exhibited by the cosmic rays, and before drawing the final conclusions its significance will be discussed. For it means that at the time these rays enter the earth's atmosphere, they are practically pure ether waves or photons. If they were high-speed electrons or even had been appreciably transformed by Compton encounters in passing through matter into such high-speed electrons or beta rays, these electrons would of necessity spiral about the lines of force of the earth's magnetic field and thus enter the earth more abundantly near the earth's magnetic poles than in lower latitudes. This is precisely what the experiments made during the last summer at

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[2] See articles by Millikan and by Millikan and Cameron, Phys. Rev., Dec. 1, 1930, and Feb. 1, 1931. Also Nature, Oct. 24, 1931.

Churchill, Manitoba (lat. 59° N.), within 730 miles of the north magnetic pole, showed to be not true, the mean intensity of the rays there being not measurably different from that at Pasadena in latitude 34° N.

Nor is the conclusion that the cosmic rays enter the earth's atmosphere as a practically pure photon beam dependent upon these measurements of last summer alone. It follows also from the high altitude sounding-balloon experiments of Millikan and Bowen in April, 1922, taken in connection with the lower balloon flights of Hess and Kolhörster in 1911–1914. For in going to an altitude of 15.5 km we got but one-fourth the total discharge of our electroscope which we computed we should have obtained from the extrapolation of our predecessors' curves. This shows that somewhere in the atmosphere below a height of 15.5 km the intensity of the ionization within a closed vessel exposed to the rays goes through a maximum, and then decreases, quite rapidly, too, in going to greater heights. We have just taken very accurate observations up to the elevation of the top of Pikes Peak (4.3 km), and found that within this range the rate of increase with altitude is quite as large as that found in the Hess and Kolhörster balloon flights, so that there can be no uncertainty at all about the existence of this maximum. Such a maximum, however, means that the rays, before entering the atmosphere, have not passed through enough matter to begin to get into equilibrium with their secondaries—electron-rays + or −, rays and photons of reduced frequency—in other words, that they have not come through an appreciable amount of matter in getting from their place of origin to the earth.

This checks with the lack of effect of the earth's magnetic field on the intensity of the rays; and the two phenomena, of quite unrelated kinds and brought to light years apart, when taken together, prove most conclusively, I think, that the cosmic rays can not originate even in the outer atmospheres of the stars, though these are full of hydrogen and helium in a high-temperature state, but that they must originate rather in those portions of the universe from which they can come to the earth without traversing matter in quantity that is appreciable even as compared with the thickness of the earth's atmosphere—in other words, that they must originate in the intensely cold regions in the depths of interstellar space.

Further, the more penetrating the secondary rays produced by photon encounters, the greater the thickness of matter that must be traversed before the beam of pure photons which enters the atmosphere gets into equilibrium with its secondaries; and until such equilibrium is reached, the apparent absorption coefficient must be less than the coefficient computed for pure photons with the aid of any

formula from the energy released in the process from which the radiation arises. Now the Bothe-Kolhörster experiments of about a year ago seem to show that when the energies of the incident photons are sufficiently high, the rays are abnormally penetrating; so that it is to be expected that, for the cosmic rays produced by the formation of the heavier of the common elements like silicon and iron out of hydrogen, the observed absorption coefficients will be somewhat smaller than those computed from the energy available for their formation. This is indeed the behavior which our cosmic ray depth-ionization curve seems to reveal. At the highest altitudes at which we have recently observed (14,000 ft.), the helium rays have reached equilibrium with their secondaries, and the observed and computed coefficients agree reasonably well. For the oxygen rays the observed coefficient is a little lower than the computed value—about 17 per cent lower; for the silicon rays still lower—about 30 per cent; and for the iron rays considerably lower still—about 60 per cent; all in general qualitative agreement with the theoretical demands as outlined.

The foregoing results seem to point with some definiteness to the following conclusions:

1. The cosmic rays have their origin not in the stars but rather in interstellar space.

2. They seem to be due to the building up in the depths of space of the commoner heavy elements out of hydrogen, which the spectroscopy of the heavens shows to be widely distributed through space. That helium and the common elements of oxygen, nitrogen, carbon, and even sulphur, are also found between the stars is proved by Bowen's beautiful recent discovery that the "nebulium lines" arise from these very elements.

3. These atom-building processes can not take place under the conditions of temperature and pressure existing in the sun and stars, the heats of these bodies having to be maintained presumably by the atom-annihilating process postulated by Jeans and Eddington as taking place there.

4. All this says nothing at all about the second law of thermodynamics or the Wärme-Tod, but it does contain a bare suggestion that if atom formation out of hydrogen is taking place all through space, as it seems to be doing, it may be that the hydrogen is somehow being replenished there, too, from the only form of energy that we know to be all the time leaking out from the stars to interstellar space, namely, radiant energy. This has been speculatively suggested many times before, in order to allow the Creator to be continually on his job. Here is, perhaps, a little bit of experimental finger-pointing in that direction. But it is not at all proved or even

perhaps necessarily suggested. If Sir James Jeans prefers to hold one view and I another on this question, no one can say us nay. The one thing of which we may all be quite sure is that neither of us *knows* anything about it. But for the continuous building up of the common elements out of hydrogen in the depths of interstellar space the cosmic rays furnish considerable experimental evidence. I am not unaware of the difficulties of finding an altogether satisfactory kinetic picture of how these events take place, but acceptable and demonstrable facts do not, in this twentieth century, seem to be disposed to wait on suitable mechanical pictures. Indeed, has not modern physics thrown the purely mechanistic view of the universe root and branch out of its house?

ASSAULT ON ATOMS[1]

By Arthur H. Compton

[With 2 plates]

Twenty-five hundred years ago, Thales, the first true scientist of ancient Greece, undertook to solve the problem, "Of what and how is the world made?" Almost a hundred generations have passed and the problem is not yet solved.

Democritus and his followers thought they had found the solution. Everything is made of atoms. "According to convention there is a sweet and a bitter, a hot and a cold, and according to convention there is color. In truth there are atoms and a void." Thus, in terms of motions of minute particles the ancient Atomists accounted for their world. Mountains and seas, trees and people, even life and thoughts, were thus explained.

But Socrates and Plato would have none of their atoms. Did they not in Democritus' hands rob men of their personality? Atoms are thus worse than useless, for they destroy the basis of morality. Here in Athens, around the question of atoms, was staged the first great battle between science and religion. Epicurus and Lucretius took up the cudgels on behalf of the atomists, but Plato carried the day, and atoms were forgotten until the revival of scientific thought during the Renaissance. Though our present day atomic theories are based on much firmer foundations than those of Democritus, they owe their origin to his ideas, transmitted down through the centuries.

A few years ago we were camped beside a mountain lake in the foothills of the Himalayas, studying cosmic rays. The warm air from the plains of India was carried up over a range of mountains, and came down again into the beautiful Vale of Kashmir. Clouds were continually forming as the air, cooled by expansion as it came up the mountain side, became supersaturated with moisture. But after passing the peak of the range, the air was warmed by com-

[1] Read before the American Philosophical Society, Apr. 23, 1931. Reprinted by permission from Proceedings of the American Philosophical Society, vol. 70, No. 3, 1931.

pression as it sank to lower levels, and the clouds evaporated into thin air.

It was while watching such clouds in his native hills of Scotland that C. T. R. Wilson conceived his beautiful laboratory experiments on clouds. Of course he couldn't bring the mountains into his laboratory, but he could expand his moist air in a cylinder with a piston at one end. He made his cylinder of glass in order to see what was going on. I have one patterned after his design here in my hand. Here are the glass top and sides, with the whole vessel partially filled with inky water. There is a lamp beside the glass cylinder so we can see better what is going on. I can compress the air in the glass chamber by squeezing the bulb. We let the air remain under this pressure for a moment, until it becomes saturated with moisture, and then allow it to expand. As it expands the air cools and a cloud forms in the chamber just as it did on the mountain top.

Did it ever occur to you that, when a cloud forms, each little drop of moisture in the cloud must condense on something? Usually it condenses on a speck of dust floating in the air, and after a rainstorm these dust particles are carried to the ground and the air is beautifully clear. But when the dust has been removed, what can the drops condense on? There are always in the air some broken bits of atoms and molecules, which we call ions. These ions are produced by rays from radioactive substances in the ground and other sources. So, Mr. Wilson tried the experiment of placing a speck of radium in his expansion chamber, to see what kind of clouds would be formed. Let's see what happens when we repeat his experiment. Those of you who are near enough will see the little white lines radiating out from the tip of the glass rod which carries the radium. These little white lines are tiny clouds of water drops, condensed on the ions left along the paths of particles shot out by the radium. It is clear that particles of some kind are coming from the radium. What are they?

A series of photographs will illustrate what is happening in this chamber. A picture taken from above (pl. 1, fig. 1) shows the glass walls of the chamber, and the rod on which the speck of radium is placed. The more or less diffuse lines are the clouds of water drops that mark the paths of the particles ejected from the radium.

What are these particles? Let us call them alpha particles, in order not to imply anything about what they are, and look into their properties. Plate 1, Figure 2, shows a sharper photograph, each line a thin straight cloud, marking the path of an alpha particle. Rutherford (recently made Lord Rutherford in recognition

of his work with atoms) caught a large number of these particles to find out what they were when there are enough of them to handle. Niton is a radio-active gas, a hundred thousand times as active as radium. He compressed some of this gas into a fine glass tube with walls so thin that the alpha particles would pass right through. After a few days he noticed gas collecting in the space surrounding this tube, and this gas he forced into a fine tube above. On passing an electric discharge through the tube and looking through a spectroscope at the light emitted, he saw the brilliant spectrum characteristic of the gas helium.

Many of you know the romance of helium. Observed many years ago by Lockyer in the spectrum of the sun, it remained unknown on the earth for a generation until Rayleigh and Ramsay, making a precise measurement of the density of the nitrogen in the air, found it different from the nitrogen prepared in the laboratory. Search for the cause of the discrepancy revealed a whole series of new gases—argon with which our incandescent lamps are filled, neon with which we advertise our wares in blazing red, helium with which we now fill our dirigibles, and two others, krypton and xenon, which are now of great value in certain laboratory experiments. Thus was helium found, and here we see it being formed—the birth of helium atoms. For these alpha particles are none other than atoms of helium gas.

We can count these atoms one by one as they come from a preparation of radium. It might be done using an expansion chamber of this type, and counting the tracks as they appear. A better method is to allow the atoms to enter an electrical counting chamber. Each particle then can make its record on a moving film, as we see in Plate 1, Figure 3. Every little peak here marks the birth of a helium atom from its parent radium.

Imagine that we have thus counted all the atoms of helium that come through the walls of Rutherford's glass tube, and make the gas that he observed in his spectroscope. How many atoms would we have? In a little glass bulb the size of a large pea, filled with helium at atmosphere pressure, the number of atoms is about 1 with 19 ciphers after it. Perhaps that doesn't mean much to you. Let me put it this way. Two thousand years ago Julius Caesar gave a dying gasp, "Et tu Brute?" In the intervening millenniums the molecules of air that he breathed out with that cry have been blown around the world in ocean storms, washed with rains, warmed by the sunshine, and dispersed to the ends of the earth. Of course only a very small fraction of these molecules are now in this room; but at your next breath each of you will probably inhale half a dozen or so of the molecules of Caesar's last breath.

Molecules and atoms are very tiny things; but there are so many of them that they make up the world in which we live.

The story is told of Lord Kelvin, a famous Scotch physicist of the last century, that after he had given a lecture on atoms and molecules, one of his students came to him with the question, "Professor, what is your idea of the structure of the atom?" "What," said Kelvin, "the *structure* of the atom? Why, don't you know, the very word 'atom' means the thing that can't be cut. How, then, can it have a structure?"

"That," remarks the facetious young man, "shows the disadvantage of knowing Greek."

Does the atom have parts?

THE ELECTRON

Do you see the faint little trail at the bottom of Plate 1, Figure 4? It appears to be due to something much smaller than the particle which made the broad bright trail above it. If we called the one an alpha particle, let us call the other a beta particle, and try to find out what kind of thing it is.

Plate 1, Figure 5 shows a large number of these beta particles, that have been knocked out of air molecules by the action of X rays. You can see where the X rays passed through the middle of the chamber. Now every substance has its own peculiar kind of atoms. Iron atoms differ from oxygen atoms, and these from atoms of carbon and so on. But these beta particles are all alike, as far as we can tell, and they can be knocked out of anything. Had we put into the chamber fried eggs or a platinum wrist watch, the same kind of beta particles would have been observed. Thus beta particles are things which go to make up all kinds of matter. They are more fundamental even than atoms.

But what are these beta particles? In the first place they carry an electric charge. Notice in Plate 2, Figure 1 how their trails are curled up if a magnet is held near the expansion chamber. This is because the moving electric charge acts like a wire carrying an electric current, and the particles form the armatures of tiny electric motors.

Professor Millikan, a member of our society, spent years at the University of Chicago in measuring the charge carried by one of these little particles. He built himself an electroscope in which a tiny drop of oil took the place of the usual gold leaf, and he would catch these beta particles on his oil drop. Every particle carried the same charge, he found. It was also the same charge that a hydrogen ion carries when water is dissociated into oxygen and hydrogen by the passage of an electric current.

Because it carries this unit of electric charge, which seems to be an indivisible unit, these beta particles were called *electrons*, and by that name they have become familiar.

These electrons have been weighed, too, and their weight is found to be very small indeed. The atom of hydrogen is the smallest atom we know, and as we have seen, it is a very tiny thing. But an electron weighs only 1/1845 as much as does a hydrogen atom. Thus we were correct in guessing that the beta particle which made the faint trail was much smaller than the alpha particle that made the broad bright streak on an earlier photograph.

The electron is indeed one of the components of which the atom is built. We can in fact count the number of electrons that each atom has. Hydrogen has 1 electron, helium 2, lithium 3, and so on. Oxygen has 8 electrons in each atom, iron 26, and uranium, the heaviest atom of all, has 92 electrons.

THE NUCLEUS AND THE PROTON

But this is only a part of the story. The electrons are all particles of *negative* electricity. The atom itself is electrically neutral, and must therefore have in it some positive electricity to neutralize the negative electrons. If time were available, I should describe for you the beautiful experiments carried out by Rutherford and Aston in Cambridge, Dempster at the University of Chicago, and others, which have shown that this positive electricity is concentrated in a very small nucleus, which though much smaller in size that the atom has yet nearly all the atom's weight.

The careful experiments of Dempster and Aston have shown that the weights of the nuclei of the various atoms, such as oxygen, nitrogen, sodium, and the rest, are whole multiples of a unit which is nearly equal to the weight of the hydrogen nucleus. This suggested that the various atomic nuclei are built up of hydrogen nuclei. This idea was supported by the fact that the electric charge carried by the various atomic nuclei is always an integral multiple of the charge carried by hydrogen nucleus.

Many attempts have been made to make one element out of another. This is in fact the old problem of alchemy, to make gold out of lead. The first success was got by Rutherford. He didn't get gold out of lead; but he did get hydrogen out of nitrogen and out of aluminum and other elements.

The experiment can best be shown using again our cloud expansion apparatus, as has been done for example by our fellow member, Professor Harkins. Plate 2, Figure 2 shows a group of alpha particles shooting through nitrogen gas. Most of them go straight

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to the end of the path, and this is remarkable, for each alpha passes right through tens of thousands of nitrogen atoms before its flight is stopped. But here we see a really surprising occurrence. The alpha particle dives into a nitrogen atom, and out of it emerges a smaller particle, which goes out leaving a thin straight trail. The nitrogen nucleus with the alpha particle now attached moves heavily along in a different direction. The alpha particle has served as a hammer to knock a hydrogen nucleus out of a nitrogen atom.

Similar experiments have been done with many other elements, and most of the lighter ones have thus been disintegrated, expelling always a hydrogen nucleus. Thus we may take this nucleus, like the electron, as a component of which the various atoms are built. We give to the hydrogen nucleus now the name of *proton*, i. e., the original or fundamental thing. Out of protons and electrons we believe all the 92 different kinds of atoms are built.

HOW THE ATOM IS BUILT

Old Ptolemy, the ancient Greek astronomer, knew that there was a sun and a moon, the earth, and the planets, but he didn't know what the solar system is. When Copernicus and Galileo showed, however, that there is a sun, around which revolve planets in definite orbits, then men felt that they had become acquainted with their world. So, though we have found the parts of which the atom is made, we really don't know the atom until we know how these parts are put together.

Perhaps the best way to find out how something is made is to look at it. If it is something like a watch, which we can hold in our hands, this is comparatively easy. If it is the cell structure of a muscle that we wish to examine, we put it under a microscope. But some things are too small to see, even in a microscope. By using ultra-violet light of wave length shorter than ordinary light, we can photograph such things as typhoid bacilli with increased sharpness. But atoms are too small even for this.

Now, X rays have a wave length only a ten-thousandth that of light, and if we could use them in a microscope it should be possible for us to observe even the tiny atoms. Unfortunately, we can not make lenses that will refract X rays, and even if we could, our eyes are not sensitive to X rays. So it would seem that we shall never be able to see an atom directly.

It is nevertheless possible for us in the laboratory to get by more round-about methods precisely the same information about an atom that we should if we could look at it with an X-ray microscope. I have spent a large part of the last 16 years trying to find what the atom looks like, and it has become something of a game with me.

Last summer while spending a brief vacation in northern Michigan, I noticed a fuzzy ring, not very large, around the moon. Half an hour later the ring was perceptibly smaller, and within an hour we had to come in out of the rain.

This ring was due to the diffraction of the moonlight by tiny water droplets that were beginning to form a cloud. The size of the ring depends upon the size of the water drops—if the drops are small, the ring is big, and vice versa. So when the ring grew smaller it meant that the drops were growing larger. Soon they would fall as rain.

Our method of studying atoms is very similar to this method of finding out the size of the droplets in a cloud. Instead of the moon we use an X-ray tube, and in place of the cloud of water droplets we use the atoms in air or helium. For the wave length of the X rays bears about the same ratio to the size of a helium atom that a light wave bears to a droplet of water in a fog. The helium atoms spread the X rays out into a halo. This halo, now of X rays scattered by the helium atoms, corresponds precisely to the ring around the moon diffracted by the cloud droplets. Likewise here, from the diameter of this halo, we can estimate the size of the helium atom. We can also tell pretty much what it looks like, just as if the atom were under the microscope.

Plate 2, Figure 3, shows how the helium atom would look if we were to see it with an X-ray microscope. The picture is drawn carefully from the data we have got from the diffraction halos. Of course, it is highly magnified, about a thousand million times. Such a magnification would make a pea appear as big as the earth.

In the middle of this fuzzy ball somewhere is the nucleus of the helium atom, which has in it the protons. This fuzzy atmosphere is due to the electrons. We noted above that the helium atom has only two electrons in it. You may wonder how with only two electrons the atom can seem so diffuse. Did you ever see the boys on the Fourth of July waving the sparklers to make circles or figures eight? Of course the sparklers weren't in the form of circles; they appeared that way because they moved so fast. So here, the electrons give this continuous, diffuse appearance to the atom because they are now here and now there, and we have caught a "time exposure" of their average positions. This is, of course, what we would see if we could look at the atom.

There have been 57 varieties of atomic theories proposed. Lord Kelvin thought the atom was something like a smoke ring; J. J. Thomson said it was a sphere of jelly. Rutherford called it a miniature solar system, while Bohr and Sommerfeld calculated pre-

cisely the orbits of the planetary electrons revolving about the central nucleus. Lewis and Langmuir objected, and said the atom is a cube. "Not so, it's a tetrahedron," claimed Lande. "Quite a mistake; it's a diffuse atmosphere of electricity around a central core," says Schrödinger. "Only it isn't diffuse electricity," complains Heisenberg, "It's electrons moving now here, now there, which make up this atmosphere."

Each of these theories has found support in that it has explained certain physical or chemical or spectroscopic properties of atoms. For the most part, each theory has been better than the one before, because it has explained the things which the earlier one described and some new thing as well. It may seem over-optimistic to suppose that there is anything final about the most recent theory. Yet the fact remains that there is one and only one such picture, namely, that of Heisenberg, that describes what we find when with our "X-ray eyes" we look into the atom.

Does this mean that the problem of the structure of the atom is solved? Not yet! We feel that we know in general outline what this electron atmosphere of the atom is like; but there's the nucleus of the atom. What is it like?

"What's the idea of bringing that up?" you ask me. "Surely that little nucleus isn't big enough to amount to anything!"

It is the nucleus of the radium atom from which the alpha particles came. Did it occur to you that those alpha particles carry a tremendous amount of energy? It is about a million times as much as is released when a molecule of TNT explodes. It is only because they are liberated one at a time that the alpha particles make so little impression.

Did you ever pause to wonder where all the energy of the sun comes from which it is pouring out as heat? If it were made of pure coal burning in oxygen, the sun could shine with its present brilliance for only a few thousand years, less than the era of history, before it would be reduced to a cinder. Even if it were composed of uranium or radium, and got its heat from their disintegration, it would last only for a few billion years, which is about the age of our own earth; yet our geological records indicate no change in the sun's brightness over this vast period. The best astronomical evidence indicates that the sun must be at least a thousand billion years old. What is the enormous supply of energy which has kept it hot for so long a time? Professor McMillan has pointed out that apparently the only way to explain the sun's long life is to suppose that the sun is consuming itself. If under the extreme pressure and temperature of the sun's interior the electrons and protons in an atom should come together and neutralize each other, all of their

energy would be liberated and add to the sun's heat. Such a process would release energy almost beyond belief. From five drops of water, if we could thus squeeze out all the energy, we should be able to run all the power stations in Philadelphia for 24 hours.

Is it possible for man to tap these great stores of energy? We do not know. We know the energy is there, and the evidence is strong that it is being liberated in the sun and stars. But under what conditions? Perhaps we can not realize the proper conditions here on the earth. In any case it is our job—the physicists' job, that is—to find out whether this energy can be used, and, if so, how.

If we are to find the conditions for the release of these vast stores of energy, we must acquaint ourselves with the atomic nucleus, for it is there that the energy lies. Studies of the band spectra of molecules have shown us something about the rotation of the nucleus. The masses of the nuclei and their electric charges have been measured by the help of magnetic spectrographs and scattered X rays. Attempts have been made to disintegrate atomic nuclei by bombardment with high speed electrons shot by high voltages. But by far the most fruitful tool for studying the nucleus has been radioactivity.

Experiments with scattered alpha rays have shown the minute size and relatively large mass of the nucleus. They have enabled us to measure its charge and even to estimate the field of electric force in its neighborhood. Further information on the latter point is given by the speed with which the alpha particles are ejected from the radioactive nucleus. Combining the evidence from these alpha ray experiments, it becomes evident that surrounding the nucleus there is a " potential wall " which prevents alpha particles that are outside from entering the nucleus and those on the inside from escaping. We are thus afforded a basis for developing a quantum theory of radioactive disintegration according to which the probability of an alpha particle jumping this wall is greater if it has large energy, and a qualitative explanation of one of the fundamental laws of radioactivity is obtained. Studies of the sharpness of gamma ray lines suggest a nucleus in which planetary alpha particles correspond to the electrons of the outer atom; though how these particles are held together remains unknown. Similarly the condition of the electrons in the nucleus remains unsolved. There is no gamma radiation that can be traced to these electrons, and when they appear as beta particles their energies are distributed over broad bands. Though much new light is shed by these studies in radioactivity, the nucleus of the atom, with its hoard of energy, thus continues to present us with a fascinating mystery.

Thus our assault on atoms has broken down the outer fortifications. We feel that we know the fundamental rules according to which the outer part of the atom is built. The appearance and properties of the electron atmosphere are rather familiar. Yet that inner citadel, the atomic nucleus, remains unconquered, and we have reason to believe that within this citadel is secreted a great treasure. Its capture may form the main objective of the physicists' next great drive.

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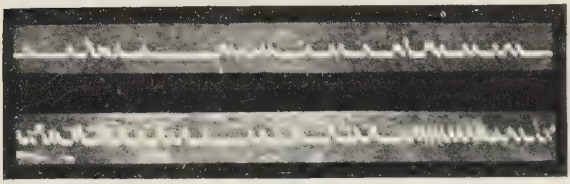

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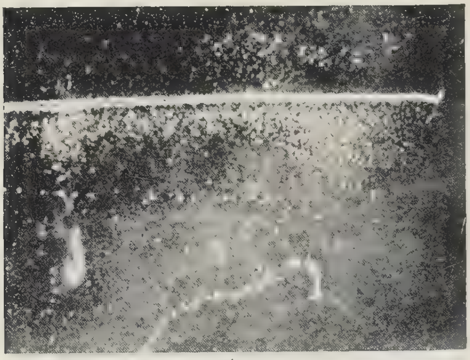

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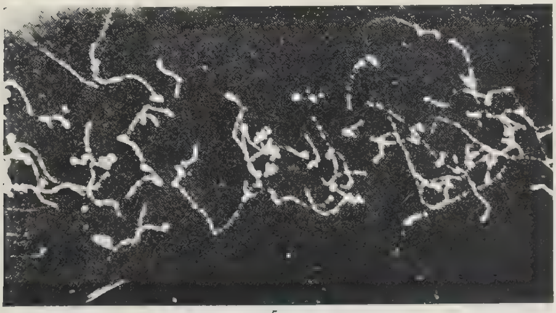
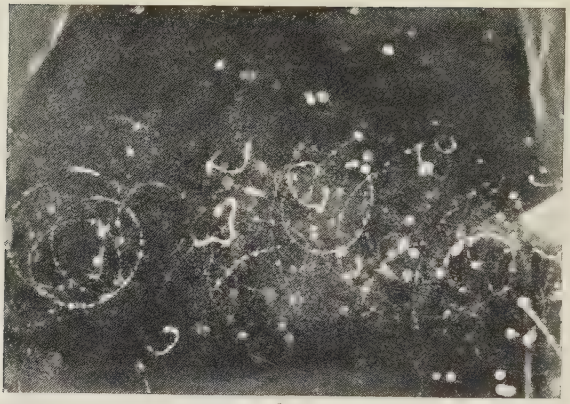


5

1, Tracks of alpha particles (helium atoms) made visible by condensing clouds along their paths (Wilson); 2, helium atoms ejected from radium (Wilson); 3, counting atoms. Each peak marks the entrance of one helium atom into the counting chamber (Geiger and Rutherford); 4, trails of alpha and beta particles (Wilson); 5, beta particles ejected from air by X rays (Wilson)



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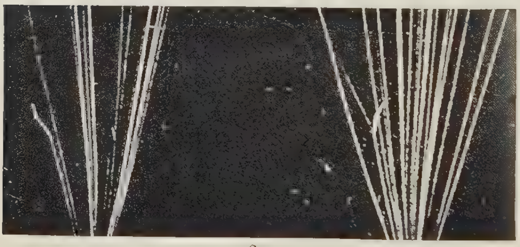

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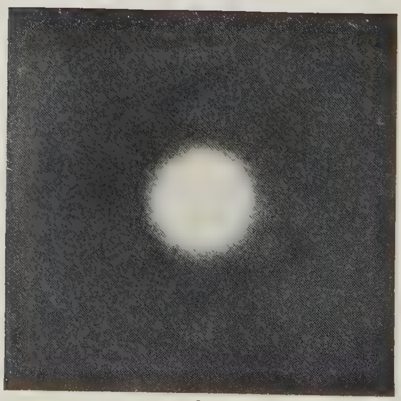

3

1, Beta particles (electrons) curved by magnetic field (Skobeltzyn); 2, alpha particle knocking hydrogen nucleus out of nitrogen atom (Blackett); 3, "appearance" of a helium atom, as found by X rays (Langer)

TWO-WAY TELEVISION [1]

By Herbert E. Ives
Electro-Optical Research Director, Bell Telephone Laboratories

[With 6 plates]

Ever since the initial demonstration of television both by wire and by radio at Bell Telephone Laboratories in 1927, experimental work has been steadily pursued in order to learn the problems and the possibilities of this newest branch of electrical communication. The latest development to be demonstrated is that of two-way television as an adjunct to the telephone. As a result of our development work, there is now [2] set up an experimental and demonstration system between the headquarters building of the American Telephone & Telegraph Co. at 195 Broadway and the building of the Bell Telephone Laboratories at 463 West Street, New York City, 2 miles away. This system makes it possible to experiment with a method of communication in which the parties engaged not only speak with each other but at the same time see each other. Study of this system will serve to give information on the importance of the addition of sight to sound in communication and will give valuable experience in handling the technical problems involved.

In principle the 2-way television system consists of two complete systems of the same sort as those used for 1-way transmission in the demonstration from Washington to New York City in 1927. In place of a scanning disk and set of photo-electric cells at one end for generating the television signals and a single disk and neon lamp at the receiving end for viewing the image, there are in the 2-way system two disks at each end and a bank of photo-electric cells and a neon lamp at each end. One of the disks, which in the system as constructed, is of 21-inch diameter, serves to direct the scanning beam from an arc lamp onto the face of one of the parties to the conversation. Three banks of photo-electric cells, making 12 in all, are arranged at either side and above the person's face and serve to pick up the reflected light and generate the television signals.

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[1] Reprinted by permission from a pamphlet issued by the Bell Telephone Laboratories.
[2] Apr. 9, 1930.

The second disk, which is 30 inches in diameter, is placed below the sending disk and exposes through its holes the neon lamp, which the observer sees through a magnifying lens in a position slightly below that of the scanning beam. This neon lamp is, of course, actuated by the signals coming in from the distant end of the system, where there is a similar arrangement of two disks, photo-electric cells, and neon lamp.

The two parties to the conversation take their places in sound-proof and light-proof booths, where, sitting in front of the photo-electric cells, they look at the image of the person at the other end

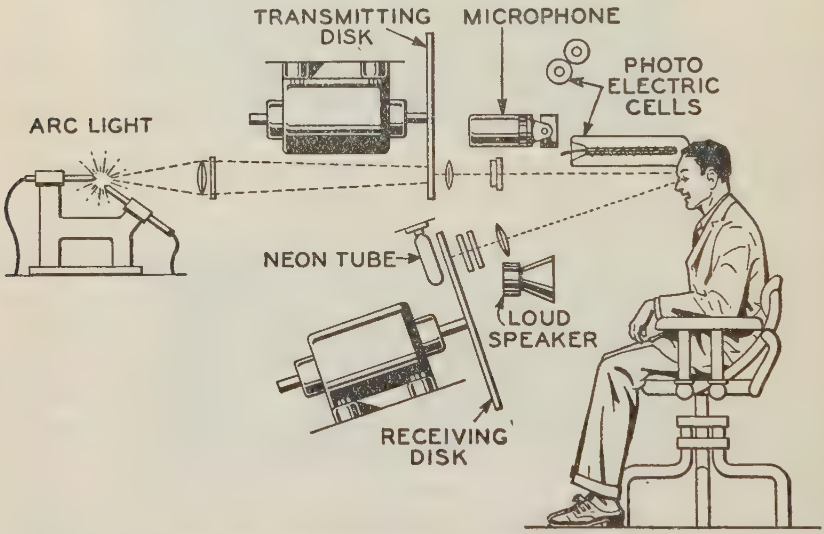


FIGURE 1.—Two-way television is essentially the same in principle as the television demonstrated three years ago. A beam of light from an arc light is thrown by a scanning disk on the speaker's face, and reflected light is picked up by photoelectric cells and transmitted electrically to the distant end. The incoming image is seen by means of the lower scanning disk and a neon tube. A concealed microphone and loud speaker act as speech terminal elements to complete the television-telephone system

at the same time that the scanning beam plays over their faces. A problem of illumination is immediately encountered in that the scanning beam is of necessity intensely bright and tends to dazzle the eyes to the extent that the somewhat faint neon lamp image is hard to see. This difficulty is met by using light for scanning to which the photo-electric cells are extremely sensitive, but to which the human eye is relatively insensitive, that is, blue light. By interposing a filter in the path of the scanning beam, the spot of light in the lens which projects it is seen as a blue disk of light not bright enough to interfere with clear vision of the neon lamp which provides the image of the person located at the distant end.

In our original demonstrations of 1-way television, scanning disks were used which had 50 holes arranged in a spiral. With this number of holes it is possible to secure a definitely recognizable representation of the human face. It was decided, however, that for the 2-way system a degree of definition should be provided such that faces were rendered in an entirely recognizable and satisfactory manner. Accordingly the number of scanning holes has been increased to 72, which provides just twice the number of image elements. The transmission band is, of course, doubled by this change, requiring wire connections of considerably higher quality than heretofore. When a 72-hole scanning disk is used, the component frequencies of the image signal encompass a range of from 10 cycles to 40,000 cycles per second, whereas intelligible speech may be reproduced by a signal wave whose component frequencies cover a range of 2,500 cycles per second. This comparison indicates roughly how much more difficult it is to transmit high-quality television images than it is to transmit ordinary speech. In general the electrical features of the apparatus are similar to those previously used, although in the interval improvements and refinements have been made in many directions.

Light reflected into the photo-electric cells gives rise to an alternating electric current whose effective value is of the order of a ten-thousand-millionth ampere. The neon glow lamp on which the image is received at the distant station reproduces the image satisfactorily when the effective value of the alternating current is of the order of one-tenth ampere. This thousand-millionfold increase in current variation, considerably greater than required for the earlier 1-way system, is effected by amplifiers in which the vacuum tubes are coupled by condensers and resistances. The tubes, which operate at low energy levels, are shielded against electrical, mechanical, and acoustical interference.

For the transmission of images between 463 West Street and 195 Broadway, the appropriate stages of the amplifier systems are coupled by special transformers to telephone cable circuits equipped with special distortion correcting networks which are capable of transmitting the extremely complex current variations without distortion. The amounts of distortion inherent in other parts of the system are either kept small by design or annulled by means of correcting networks.

An indispensable part of a television system is the means for holding several scanning disks accurately at the same speed. For the 2-way television system, a simplified and improved synchronizing arrangement is used. The disks at the receiving and transmitting ends, which rotate at a speed of 18 revolutions per second, are

synchronized by means of a vacuum tube oscillator located at one end of the line and delivering a frequency of 1,275 cycles per second at a low-power level. This frequency is transmitted over a separate pair of wires. At the receiving end this frequency, through vacuum tube means, controls the field strength of the motor and thereby holds its speed exactly proportional to the frequency. In the same way, the speed of the motor at the transmitting end is controlled by a similar vacuum tube circuit so that its speed is also proportional to the frequency of the same oscillator, and thus the motors driving the scanning disks at both ends of the line are held in synchronism. By using a frequency of 1,275 cycles per second, the degree of synchronization is held within sufficiently close limits to keep the picture at the receiving end central within its frame within a small fraction of the picture width. Novel features of this synchronizing system are the use of mechanically damping couplings between the disks and the motor shafts to improve the steadiness of the image, and of an electrical phase shifter for framing the images.

The acoustic portion of the 2-way television system is unusual in that it permits simultaneous 2-way conversation without requiring either person to make any apparent use of telephone instruments. It is obviously desirable to arrange the acoustic system in this way because the ordinary telephone instrument conceals part of the face and would thus prevent the system from approximating to the conditions of ordinary face-to-face conversation. The elimination of telephone instruments is accomplished by the use of a microphone sensitive to remote sounds and a loud speaker concealed near the television image at each station. The microphone at one station is connected through suitable vacuum-tube amplifiers and a telephone circuit to the loud speaker at the other station. This permits conversation in one direction while a similar connection between the other microphone and loud speaker permits conversation in the other direction. The persons using the system then communicate as if face to face and with no telephone system apparently involved.

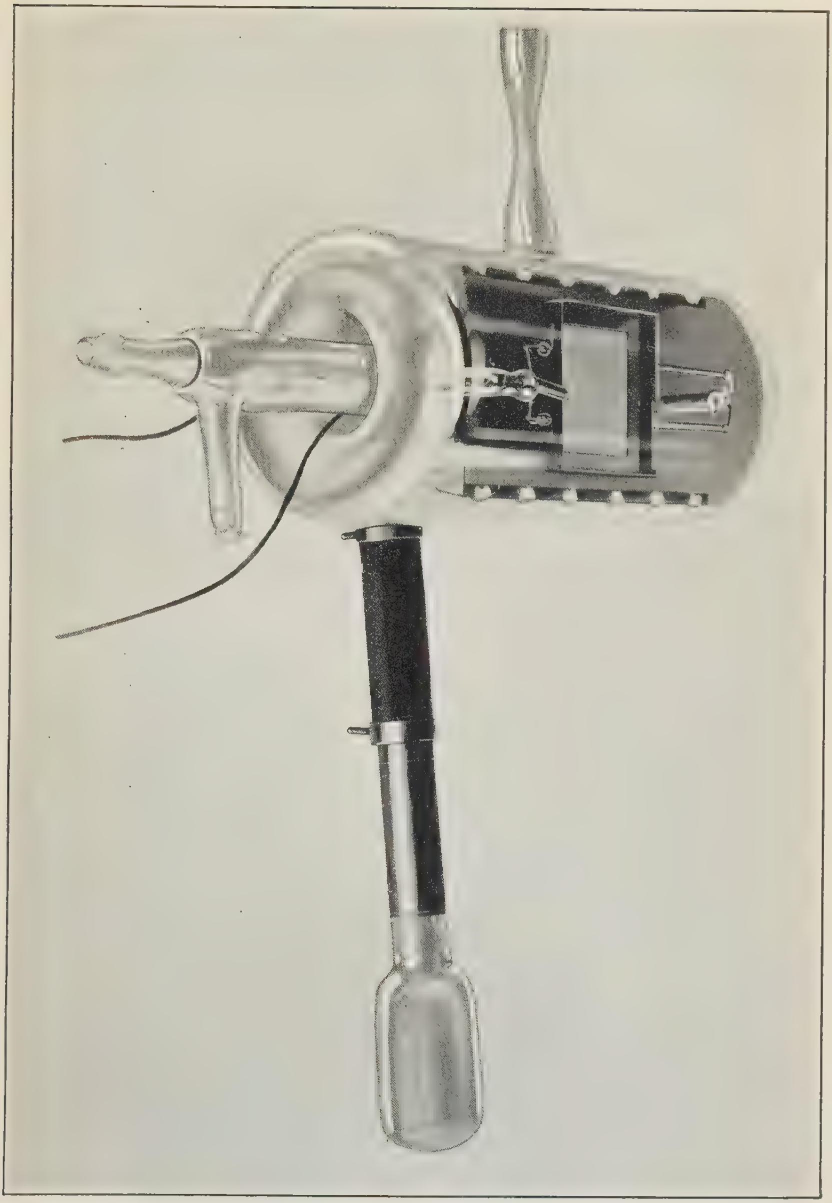
In order that the transmitted sounds be familiar and natural, distortion in the sound-transmission system has been reduced to a minimum. The microphones are of the condenser type used extensively in radio broadcasting and sound-picture recording. Being of small size, they are readily concealed near the television image in the most advantageous position for picking up the voice. The loud speaker, also of small size but capable of reproducing a broad frequency range, is likewise concealed near the television image, so that the sounds produced appear to emanate from the image itself.

This loud speaker is of the moving coil type with a small piston diaphragm.

In any system such as that described, the microphone is not capable of distinguishing between the sounds from the local speaker or from a speaker at the remote end of the circuit reproduced locally by the local loud speaker. If the sounds from the local loud speaker should be impressed upon the local microphone in sufficient magnitude, "singing" would result, and the system be no longer operable. To prevent this the microphone and the loud speaker are installed in carefully chosen positions and the inner surfaces of the sound-proof booths are specially treated to prevent as much as possible the reflection of sounds from the walls into the microphone. Under these conditions, the attenuation of sounds transmitted is of about the same magnitude as would be experienced if the listener were, say, 10 or 12 feet away, but in the same room. This acoustic illusion of distance is in harmony with the visual appearance of the television image.

In addition to the television synchronizing and acoustic circuits, others are provided for signaling and monitoring purposes. Matters are so arranged that an operator can see both the outgoing and incoming image, and by means of movable lens and prism systems can insure that the scanning beam is properly directed to correspond to the height of the observer, and that the magnifying lens in front of the receiving disk directs the image to the observer's eyes.

Operating arrangements are made so that the two parties to the conversation, after taking their positions in the booths, do not see or hear each other until adjustments are made, whereupon the operators expose the images and connect the talking circuits simultaneously. The experimental service is arranged on an appointment basis. The two parties to the conversation, having arranged with attendants at the two stations for their time, proceed to the respective booths, where they are ushered into chairs in position before the photoelectric cells and instructed as to the operation of the system. Immediately the attendant closes the booth door, the operators make the necessary adjustments; and the simultaneous sight and sound communication is carried on until, upon the parties leaving their chairs, the connections are interrupted.

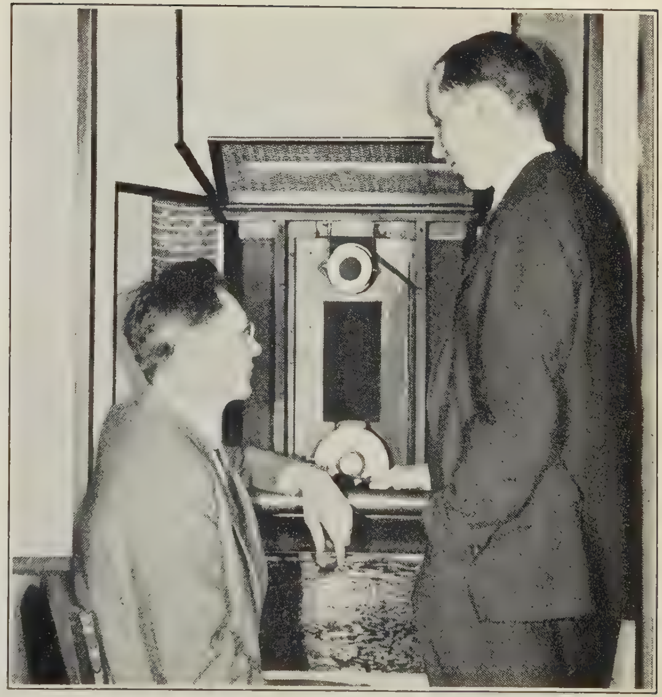


ONE OF THE WATER-COOLED NEON TUBES USED FOR THE RECEPTION OF TELEVISION IMAGES

While in operation the central rectangle glows with a pinkish light.

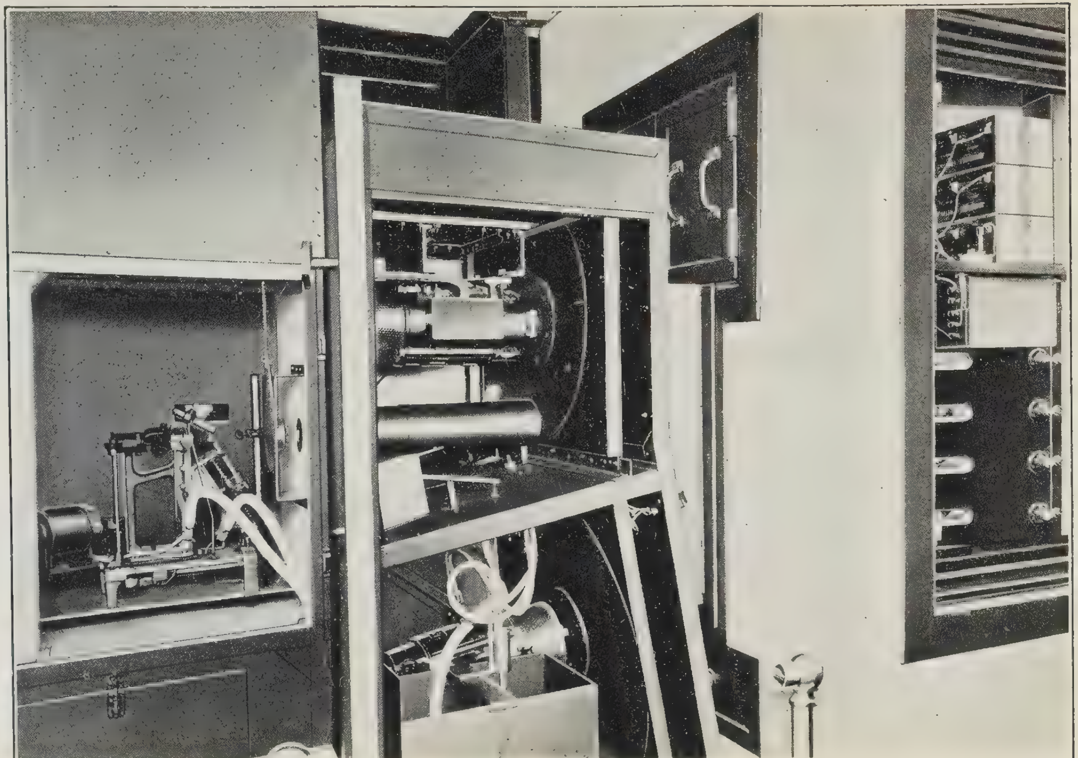
1. TWO SCIENTISTS OF BELL TELEPHONE LABORATORIES, A. L. JOHNSRUD AND DR. FRANK GRAY, IN THE TELEVISION BOOTH, ONE TERMINUS OF THE NEW TWO-WAY SYSTEM

Behind the glass plates may be seen the giant photoelectric cells—the "eyes" of the system.



2. D. G. BLATTNER AND L. G. BOSTWICK, ENGINEERS OF BELL TELEPHONE LABORATORIES, DISCUSS THE ACOUSTICAL EQUIPMENT FOR TELEPHONE TELEVISION

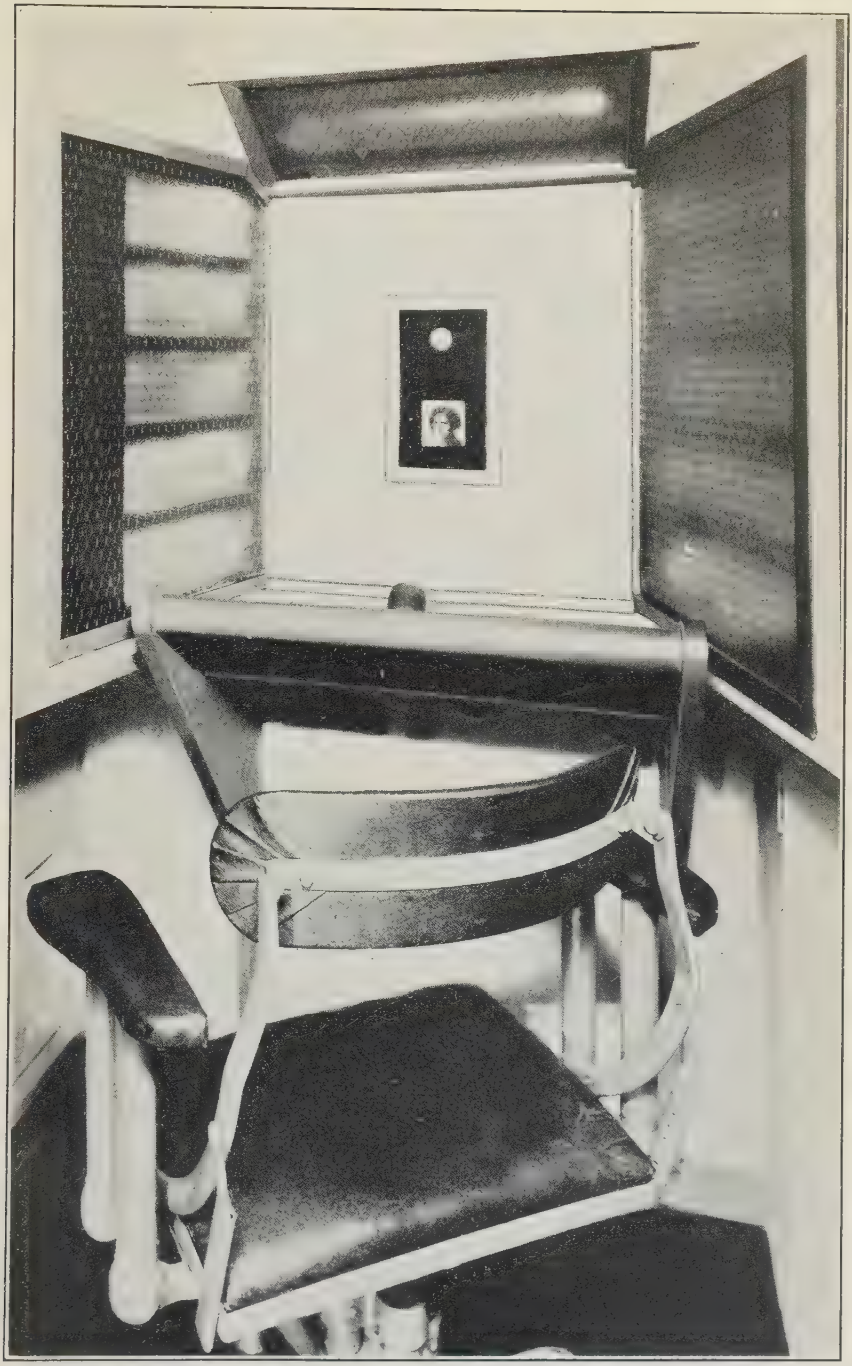
In service, the microphone (above) and loud speaker (below) are covered by a screen.



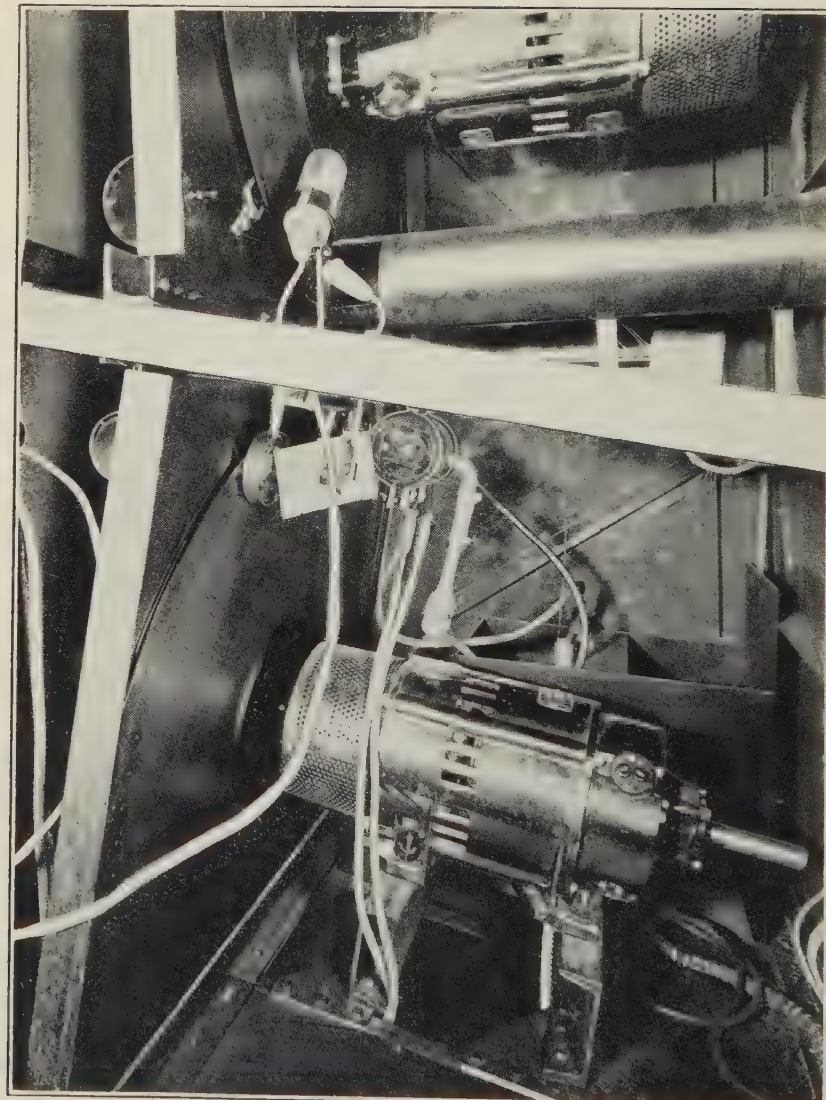
SIDE VIEW OF OPENED TELEVISION CABINETS SHOWING PHOTO-ELECTRIC CELLS AT THE RIGHT, MOTOR AND SCANNING DISK IN CENTER, AND THE ARC LIGHT AT THE LEFT

CONTROL FOR THE TELEVISION-TELEPHONE APPARATUS IS MOUNTED ON THREE PANELS

A. W. Horton and M. W. Baldwin, engineers of Bell Telephone Laboratories, are shown monitoring circuits.



INTERIOR OF TELEVISION BOOTH SHOWING POSITION OF INCOMING IMAGE AND, JUST ABOVE IT, THE HOLE THROUGH WHICH THE SCANNING BEAM IS PROJECTED



CLOSE-UP VIEW OF SCANNING DISKS, NEON LAMPS, AND THE ARRANGEMENT FOR SUPERVISION

RESEARCH CORPORATION AWARDS TO A. E. DOUGLASS AND ERNST ANTEVS FOR RESEARCHES IN CHRONOLOGY

(Presentation at Smithsonian Institution, Washington, December 18, 1931)

REMARKS OF DR. C. G. ABBOT,

Secretary, Smithsonian Institution

Mr. Chief Justice, Ladies and Gentlemen: The Research Corporation of New York is probably the only organization of its kind in existence. It sprang from the desire of a scientist to have the fruit of his scientific labors capitalized for the promotion of research. In 1911 Dr. Frederick G. Cottrell, then chief physical chemist, later director, of the United States Bureau of Mines, and his associates offered their invention for the electrical precipitation of suspended particles to the Smithsonian Institution for the benefit of science. As the Institution could not well undertake the development of a matter so likely to have commercial and legal complications, Dr. Charles D. Walcott, then Secretary of the Smithsonian, undertook with Doctor Cottrell to enlist the aid of public-spirited men of Boston and New York City to organize a nonprofit-sharing corporation for the development of the patents, and in 1912 the Research Corporation was formed.

Its purposes are to acquire inventions and patents and make them more available in the arts and industries, while using them as a source of income, and, second, to apply all profits from such use to the advancement of technical and scientific investigation and experimentation. The Research Corporation has succeeded financially so that it has built up a reserve and given large funds to scientific work. Among grants made by the corporation are several to the Smithsonian Institution for work on solar radiation and its influence on plants and animals; to the Kaiser Wilhelm Institute for Medical Research, at Heidelberg, to carry on cancer research; to the International Auxiliary Language Association for linguistic research; to Harvard University, Columbia University, Leland Stanford Junior University, Pennsylvania State College, and the Stevens Institute of Technology, in support of various projects. A grant was made to the National Research Council to assist in the publication of one of the volumes of the "International Critical Tables." A recent grant has been made to the University of California to make possible the installation of an 85-ton magnet, through which it is hoped to promote the study of atomic structure.

As the charter of the Research Corporation provides that its awards shall be made through scientific institutions, the directors have seen fit in this instance to make their awards to Messrs. Douglass and Antevs through the Smithsonian Institution. These awards were voted as of the fiscal year 1930.

The awards to Doctor Douglass and Doctor Antevs are the fourth and fifth of their kind made by the Research Corporation. The first, in 1925, went to

Dr. John J. Abel, of the Johns Hopkins University, for his work on ductless glands, animal tissues, and fluids. The second, in 1929, went to Dr. Werner Heisenberg, of the University of Leipzig, for his contribution to matrix mechanics and for his exposition of the principle of indeterminance; and the third, also in 1929, to Dr. Bergen Davis, of Columbia University, for the contribution of the Davis double X-ray spectrometer and other brilliant achievements in the field of atomic physics.

It is indeed a pleasure to have the Research Corporation represented on this platform by its president, Mr. Poillon, and by its founder, Doctor Cottrell, and to have the Smithsonian Institution represented by its chancellor, the Hon. Charles Evans Hughes, Chief Justice of the United States, who will now present the awards.

[After extemporaneous remarks by Mr. Elon Hooker, a director and past president of the Research Corporation, Doctor Abbot continued]:

I have the honor, ladies and gentlemen, to present Chief Justice Charles Evans Hughes.

REMARKS OF CHIEF JUSTICE CHARLES EVANS HUGHES

Chancellor of the Smithsonian Institution

Doctor Douglass: You have been diligently engaged for nearly 30 years in making exact measurements of conditions of former centuries as they stand recorded in the growth of ancient trees. You have pursued these studies in many lands. You have devised ingenious instruments to further your researches. Your work has been crowned with success in several directions. You have found evidences of periodicities in weather which seem to imply corresponding periodicities in the radiation of the sun. You have established an exact chronology for more than a thousand years, thus dating the prehistoric culture of the Indians of the Southwest from the timber rings of their habitations.

In recognition of these achievements, the Research Corporation of New York has awarded to you through the Smithsonian Institution a grant of $2,500. In token of this award, I now, as chancellor of that Institution, hand you this commemorative medal, and wish for you equal success in your future researches.

TREE RINGS AND THEIR RELATION TO SOLAR VARIATIONS AND CHRONOLOGY

By A. E. Douglass, *University of Arizona*

[With 5 plates]

The studies of tree rings described in this paper touch closely upon several major sciences. This is because annual rings, like annual varves, measure the passage of years, and time is a prime consideration in all branches of knowledge. Hence we find ourselves at once

making contact with botany and its associated sciences, with meteorology, and especially climatology and astronomy; with anthropology, geology, and mathematics.

At the outset I wish gratefully to acknowledge my obligation to the Carnegie Institution for its important support of these climatological studies since 1915. Especial thanks are expressed here to the National Geographic Society, through whose valued assistance the archeological material has been obtained, which has carried southwestern climatic and historic records back to 700 A. D. The American Museum of Natural History assisted in the first collection of prehistoric material. The Museum of Northern Arizona has given great help in field work and laboratory space; C. G. White gave funds for building the cyclograph; the University of Arizona has helped fundamentally by reducing teaching obligations; and now the Research Corporation of New York, through the Smithsonian Institution, has contributed its generous and highly appreciated award, for which encouragement I hereby express my sincere gratitude.

ORIGIN OF RESEARCHES

The study of tree rings began in 1901 as an astronomical investigation based on the hypothesis that the sun affects weather and weather affects trees, hence there is expectation of finding a history of sun-spot variations in the annual rings of trees. This is especially likely in a cool, dry climate like that of northern Arizona, where moisture is vital to all vegetation and where winter gives annually an emphatic resting period in the life of each tree. By 1913 precise dating of rings had been established and a new method of analysis had disclosed long-continued sequences of what appeared to be the 11-year solar cycle in the pines of Arizona. The failure of this sequence from about 1670 to 1720 caused serious questioning of its reality. The results, however, were published in 1919, with mention of this failure. But three years later Dr. E. Walter Maunder, of the Royal Observatory, Greenwich, communicated his work on the historical study of sun spots, from which he deduced a great dearth of them from 1645 to 1715. This dearth coincides closely with the failure of the trees to show this cycle.

While this cycle in the Arizona pines was evident and sometimes conspicuous, it was accompanied by other cycles, often of equal and sometimes of superior importance. For years this was puzzling and it was only in the end of 1926 that the possible relation of these other cycles to the sun-spot cycle was discovered, as will be mentioned below.

FUNDAMENTALS

In any study of tree rings, cross dating between different trees is of the first importance. This means the careful identification of each ring in different trees and the location and correction of all mistakes in each. Thus dates are carried from tree to tree and the exact year of growth of each ring is firmly established. Upon this depends directly the great precision in dating rings which many people, I am sure, fail to realize.

But cross dating does more than this. A single tree tells its own story, which may contain accidental errors. But when many trees agree with each other in successive variations over long intervals of time, then some common factor which continuously influences the whole forest is emerging. It is safe to regard this as climatic in character. Pests and fires and falling trees are local or temporary and reveal their identity. High ridges, steep slopes, and bottom lands produce effects on trees, but such effects may be identified by comparison of trees in different surface conditions. Climate, with its story of limited change from year to year, is the factor which emerges when large numbers of trees are compared.

As yet the interpretation of the story told by rings is only partly understood. A few very limited localities reveal their secrets. In northern Arizona and New Mexico, the semiarid pueblo area of the archeologists, conditions point rather clearly to rainfall as the controlling factor among the yellow pines, for that area includes the lower forest border which separates the successful forest from the deserts. Actual tests at Prescott on the western edge of this same lower border show a very close relationship between tree growth and rainfall. The similarity of growth curves in different portions of this border, hundreds of miles apart, is amazing.

As one goes nearer the center of the forest the rings become less sensitive, that is, more complacent or equal in growth. The changes from ring to ring are less abrupt. At the uppermost limits of the forest, near 9,000 feet in elevation, the pines have lost the principal changes due to rainfall and have acquired other less marked variations, doubtless largely dependent on temperature. It was the preference of the prehistoric Indians for locations on the lower and drier forest border which made the dating of their ruins much easier than might have happened.

The giant Sequoia likewise has proved a tree of the greatest importance, for cross dating can be carried continuously through almost every tree in all the groves. The rings are more complacent than those of the Arizona pines, but the sequences are so long that it is always possible to include and identify a number of telltale

rings, which by their small size denote drought years. The coast redwood is less satisfactory, but is now receiving adequate study. Earlier groups of these important trees proved to be total failures in cross dating, but a personal inspection of the forests last summer showed at once that the lower parts of the trees are so subject to erratic growth from fires and wind strains that cross dating close to the stump, as is usually done, is utterly out of the question. However, it was evident at once that higher portions of the trunk would be less subject to these injuries and we are actually now succeeding in cross dating between the tops of these trees. Yet, even so, they are not so easily dated as the species already mentioned. That could be due in part to their much divided allegiance, namely, to the rains of winter, the fogs of summer, and their almost continuous growing season throughout the year.

Trees in north Germany cross date very readily; also trees at the Arctic Circle in north Sweden. The pines of central and southern Sweden do not match as well as hoped, but the spruces cross date accurately. It is logical to suppose that trees in southern Europe or northern Africa could be cross dated as in our corresponding latitudes here. Thus many points in widely separated parts of the northern and southern hemispheres are almost certain to give results that will supply valuable climatic information. There is no doubt that the interpretation of ring width in different climatic regions needs a vast amount of detailed study, including the establishment of meteorological stations within the forests chiefly concerned.

While many regions give interlacing cycles apparently related to the 11-year cycle, certain regions give the 11-year variation without complications. The trees of north Europe, especially near the Baltic Sea, give a very perfect example of this since 1830 in curves whose maxima and minima coincide with those of the sun-spot numbers.

CYCLE ANALYSIS

Analysis of tree records has been done chiefly by the cyclograph process, which depends upon a pattern called the cyclogram, in which one can see at once not only the length but also the beginning and ending of each cycle, its steadiness or variability, its change of phase, its composition, and to a considerable extent its amplitude.

The process could be described as an interference between an approximately perfect period engraved on glass in the form of parallel, equally spaced lines and the observed maxima extended into parallel bands by a cylindrical lens. These two systems of parallels are set at an angle of about 12° to each other. In the pattern produced by the transmission of the latter through the former, the ob-

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served through the exact, different cycles appear in the form of interference bands in different directions, according to their length. Thus the cycles are automatically separated. Suitable range is secured by interposing a movable mirror between the curve and the lens and the cycle length may be read directly from the position of the mirror.

The method has great rapidity and flexibility in cycle exploration and in the separation of mixed cycles. On several occasions 42 different curves averaging 175 units in length have in three hours been analyzed for all cycles between 5.5 and 40 units by one observer. The use of this method has led me to believe that harmonics or integral parts of a fundamental are not suited to the expression of climatic cycles. Nor are we justified in assuming the sine curves that are used in harmonic analysis.

CYCLES IN MODERN TREE GROWTH

Some 52,000 measures have been made on 305 modern pines in the western United States. Their growth curves were divided into 42 groups and analyzed. In the general summary the cycles appear in a great majority of cases to be simple fractions of two or three times the sun-spot cycle. This result, reached in 1926, was held to be of sufficient importance to make a complete and independent analytical check before publishing.

Similar expressions have been reached by Abbot, Clayton, and C. E. P. Brooks. Thus, there seems support for the hypothesis that climatic cycles, which have shown such puzzling complexity, are related in a simple manner to the 11-year sun-spot cycle. One might suggest that this curious fractionizing process has something to do with interferences in any given locality between impulses coming from different centers of influence. Some recent evidence (Abbot's work on solar radiation and mine on analysis of monthly sun-spot numbers since 1750) points distinctly toward solar activity as offering a clue to this fractionizing process. That does not lessen the complexity of terrestrial distribution.

SEQUOIA CYCLES

The longest tree records were found in the giant sequoias of California, *Sequoia gigantea*. About a dozen specimens in my laboratory have records that go back to about 200 B. C. At least four carry the record back to 1100 B. C., and one extends it to 1300 B. C. The sun-spot cycle appears to be recognizable in many parts of this record, especially if one searches for the double value of something over 22 years. This subdivides at different times into halves, thirds,

quarters, and fifths. A cycle of approximately 100 years emerges in the longer records. Michelson considered that he found this cycle in the sun-spot numbers.

CYCLES IN ARIZONA PINES

The records of Arizona pines, *Pinus ponderosa*, have been extended back in a continuous series to 700 A. D. by the aid of beams from prehistoric ruins. A preliminary examination of this sequence indicates well-developed long cycles of approximately 38 years and 100 years nearly continuous through the interval, together with shorter cycles apparently related to the sun-spot cycle and one of 9.5 or 19 years (doubtless related to the 38-year cycle just mentioned).

The "Hellmann relation" is the name tentatively given to the half sun-spot cycle having a length of about 5.5 years. It is presumably an 11-year cycle with two maxima usually unequal. This cycle was described and compared with the sun-spot cycle by Hellmann in his study of the North German drainage area, published in 1906. It was observed by the speaker in 1908 in the California rainfall and in tree growth in Arizona at the same time. In 1912 it was found in north European trees with one maximum often suppressed. About 1915 it was found highly developed in the Arizona trees during the century or more following 1420, and it is now recognized to extend in a slightly modified form from 1300 to 1650, and at other places. This is considered to form a basis for reconstructing the sun-spot curve during that interval and such an attempt is being made. This relation may easily be detected in recent California tree growth and rainfall.

A shorter cycle somewhat over two years in length was noted in tree growth from the frequent occurrence of alternating sizes in successive rings. Such a cycle had been noted years before by Clayton, Arctowski, and others. From a study of rainfall near Windsor, Vt., published in 1915, this appeared to average about two and one-third years in length. The original cyclogram gives a suggestion of composite character, as if there were really two cycles, one about 2.25 and the other about 2.55 years in length.

PREHISTORIC DATING

The influence of weather and especially rainfall on the size of rings has individualized them with great uniformity over a wide extent of country. This produces distinctive configurations of large and small rings, which, like "fingerprints of Father Time," can be recognized from tree to tree. Thus, cross dating is possible over at least the northern half of the Pueblo area, and we are able to build up a long

chronology in Arizona pines, which has not only furthered our studies of climate but has supplied the building dates of a number of prehistoric ruins.

This chronology building has been done on the numerous specimens which the archeologists have obtained from prehistoric ruins since 1922. These came chiefly from Neil M. Judd, who was excavating Pueblo Bonito on behalf of the National Geographic Society. He had learned of the cross dating between different ruins and realized that such cross dating could be carried from the present time back into prehistoric ages, thus giving the actual date of the great ruin in whose repair he was engaged. His faith in the possibility of such dating resulted in important assistance from Doctor Grosvenor and the research committee of the society. And this, together with occasional friendly aid of other institutions, brought in large collections of prehistoric beams, which reached over 800 in number by 1928. These cross dated in large measure and supplied a prehistoric chronology 586 years long, and in doing so gave the relative age of more than 30 prehistoric ruins from which the specimens had come.

The problem of finding material to fill the gap between the prehistoric chronology and the historic sequence extending back to 1260 A. D. occupied us in the field trips of 1928 and 1929. Large collections were first obtained from the Hopi villages, the Pueblo structures which were still occupied by the Indians. The village of Oraibi, which 40 years ago had 900 inhabitants, was discovered to be over 500 years old. It is now largely abandoned.

But the Hopi beams did not show rings that extended back far enough, so we searched and found the ruins from which some of these Hopi people came. Thus, we succeeded in getting the first prehistoric dates at the ruin of Kawaioku, in the Jeddito area. The dates extended from 1357 to 1495. In preparation for 1929 we studied pottery chronologies and found that the beams in the gap would be associated with an orange-colored pottery, which was a transition from red to cream color. We also concluded that the existence of charcoal was very important on account of its wonderful preservations. Therefore, we must find ruins near the border of the great pine forest.

These conditions were best fulfilled at Showlow and Pinedale, 50 miles south of Holbrook. The actual gap beam was found at Showlow, June 22, 1929. It showed the well-known rings in the 1300's, then the group of microscopic rings during the drought in the late 1200's, then a splendid series to the central ring that grew in 1237. The early drought years identified on this piece were entered on our plots as an extension of the historic series, and that evening the com-

plete identity between this extension and the late prehistoric rings was firmly established. Thus the problem was solved. To our surprise there was no gap, but an overlapping of more than 20 years. It had been impossible to recognize this on account of the great drought in the late 1200's, which rendered most trees badly defective. Naturally, with so many defects during that drought interval, it has been gratifying to see since then tree records both in the Sierra Ancha Mountains of Arizona and others on the east slopes of the Jemez Mountains in New Mexico which check with precision the identity assigned to the rings in that great drought.

This solution gave at once the dating of 42 ruins; the number has now reached 75, scattered over northern Arizona, northern New Mexico, and the southern edges of Colorado and Utah. Many of these were built just before the great drought in the late 1200's. Evidently that climatic catastrophe had a profound effect on the welfare of the primitive inhabitants. Many ruins northeast of Flagstaff dated in the 1100's, and one at least lasted until 1278. The great tower in Mummy Cave ruin, in Canyon del Muerto, dated in the early years of the drought. White House ruin in Canyon de Chelly, came before 1100, as did Cliff Palace and the earlier ruins of Mesa Verde. Other ruins in Mesa Verde were built during the following 200 years. Aztec, in northwestern New Mexico, with its 450 rooms, was built in the dozen years between 1110 and 1122. Pueblo Bonito, the largest of them all, had its early construction between 919 A. D. and 950. Its major building was in the last half of the eleventh century, and its final construction extended into the early years of the twelfth century.

Thus, in closing the gap, the chronology was extended back to 700 A. D. Nearly every portion of it has been covered by at least 100 specimens. Much of the eighth century from 735 to 800 A. D. has now been covered by a considerable number of specimens from the vicinity of Flagstaff, collected by Dr. Harold S. Colton, director of the Museum of Northern Arizona, and his colleagues. And yet only one specimen, and that from Pueblo Bonito, covers with accuracy the years from A. D. 700 to 735.[1] Meanwhile further extensions are under way. Groups of specimens, collected chiefly by Earl H. Morris, have given two long sequences totaling over 600 years, which seem at present to precede the known chronology, beginning at 700 A. D.

One of the very interesting studies now in progress is being carried on by Doctor Colton, on pit houses near Flagstaff, Ariz., which were covered by a 10-inch layer of cinders from an eruption of Sunset

[1] Since this was written Miss F. M. Hawley has dated a beam from Chettro Ketl that extends our record back to A. D. 643.

Crater near by. He has already been able to make a rough estimate of the date of this eruption, and there seems little doubt that eventually it will become known with accuracy.

CLIMATE AND PREHISTORY

From the foregoing it is evident that prehistoric dating has become possible through weather effects in the rings of trees. Hence we not only get the dates of building periods in the history of the pueblos, but also we obtain some idea of the accompanying meteorological conditions. This has given us a strong impression of climatic stability, for there is no real evidence of any fundamental climatic change. The mean ring growth of a thousand years ago was not greatly different from that to-day in the same region.

But there are signs of strong pulsations or cycles. In each hundred years there has been a noticeable drought. Every third century has seen a very great drought, such as 1880 to 1904, 1573 to 1593, and 1276 to 1299. The effects of these come to us in notably defective trees and in abandoned pueblos. In the 500-year history of Oraibi even the small droughts were accompanied by decreased building.

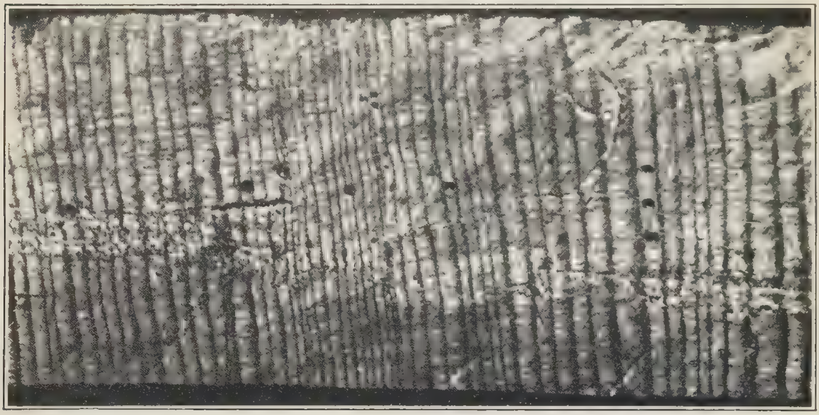
But perhaps the most significant inference is a combination of these two. Though the climate can not be said to be changing, the pulsations do not in all cases return completely to the earlier condition, for in certain areas there seems to be a drying out due to human occupation. From studies of change in ring types and from many interesting conversations with the Pueblo Indians we can reconstruct a part of this story of human adventure in a dry country. It is probable that the primitive people settled on the forest border to get best advantage of timber, water supply, and farm lands. They injured the forest by cutting trees for house building and caused the forest borders to retreat. This injured the ground cover and permitted the soil to blow away until the conservation of moisture was decreased and torrential rains tore up their farm lands and compelled them to migrate to new locations. This has actually happened in the last 40 years. Thus we find in this primitive history a human cycle of deep meaning for us who, even as these Indians, show an inclination to exhaust our natural resources without sufficiently generous thought for the future.

REMARKS OF CHIEF JUSTICE CHARLES EVANS HUGHES

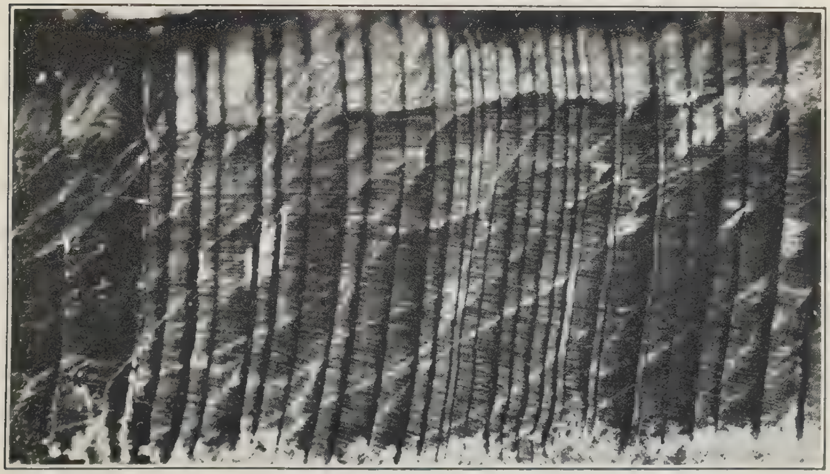
Chancellor of the Smithsonian Institution

Doctor ANTEVS: You have come to us from another land and clime where your early studies, guided by that pioneering scientist, the Baron de Geer, contributed greatly to our knowledge of the progress in Europe of that world-

1. Arizona pine forest near Flagstaff (hence forest interior); note freedom from underbrush, a dry climate character

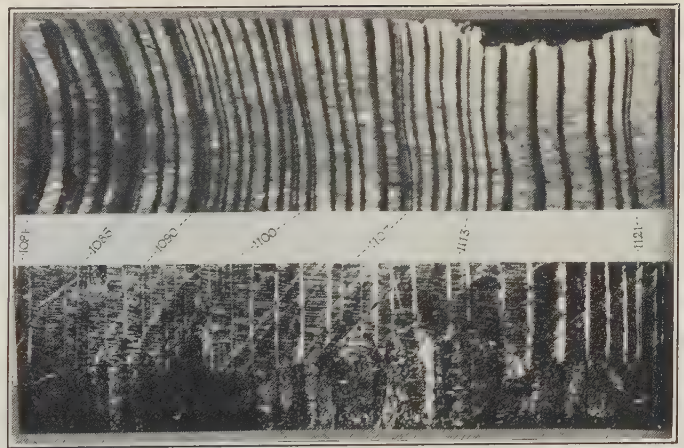


2. Drought of 1573 to 1593 in tree 5 miles south of Flagstaff, showing "forest interior" type of rings; that is, gentle changes from one ring to the next. Three dots mark the year 1600; 1590, 1580, etc., are marked by one dot.



3. Drought of 1276 to 1299 in Oraibi beam from lower (dry) forest border showing abrupt change from ring to ring. The very large ring, second from the left end, is 1275; 1299 is the last extreme drought year.

RING TYPES IN ARIZONA PINES



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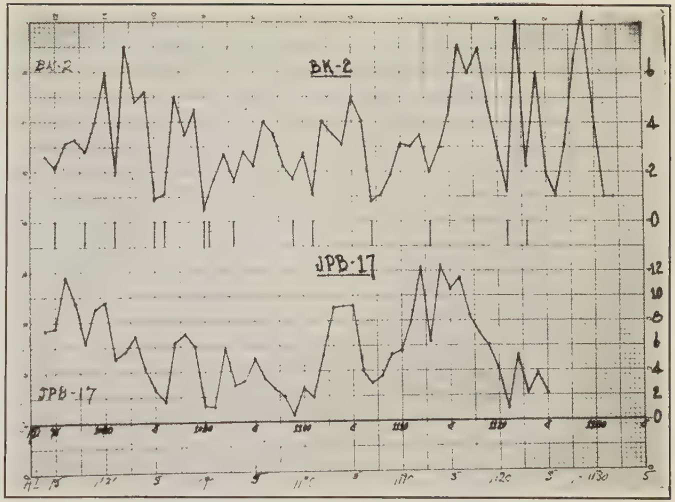

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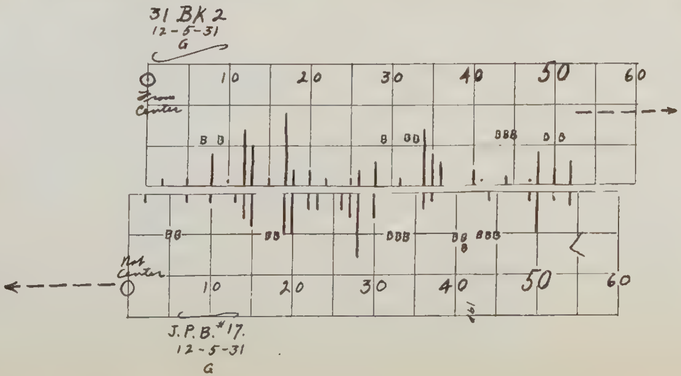
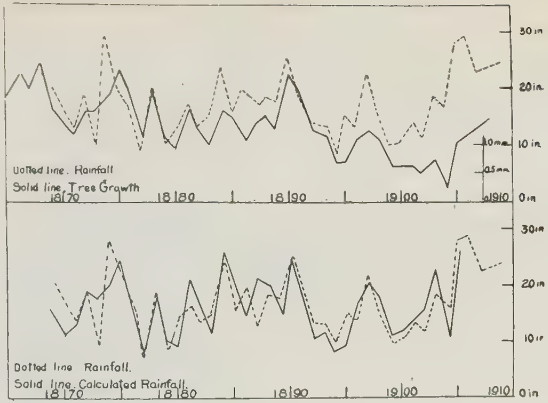


3

CROSS DATING

1. Cross dating between Betatakin Douglas fir (BK 2, above) and Pueblo Bonito pine (JPB 17, below) to illustrate chronology building. BK 2 is near the center of the tree and has therefore large curved rings and is subject to an age correction for the diminishing average size of rings on increasing distance from the center. JPB 17 is close to outside of large log with nearly straight rings. With these differences the count between drought years is identical in each. One or two rings in BK 2 are microscopic and do not show in the photograph. The upper specimen extends a century later (to right) and the lower extends nearly as much earlier (to left). Thus the two are joined into one continuous chronology. 2. Plotted curves of ring widths in specimens shown in 1. Note the agreement in location of minima. 3. Skeleton plots of same showing only the drought years; the intensity of the drought is represented in the height of the drought line. Note the agreement between the two. This plot can be made in the field without measurement and is much used in dating.



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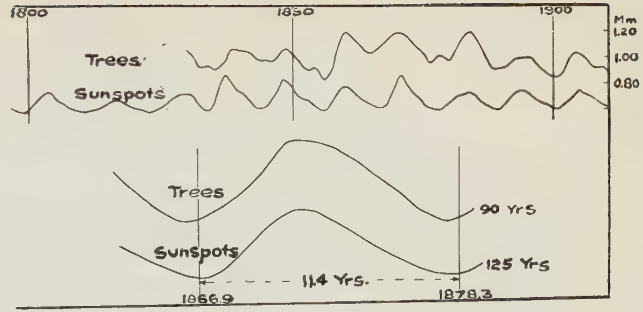

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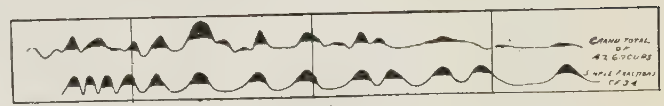

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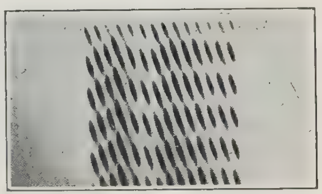

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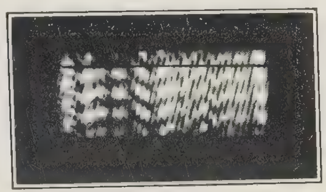

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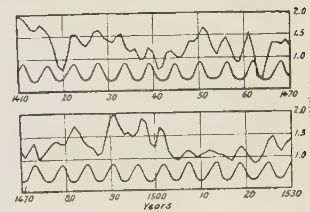

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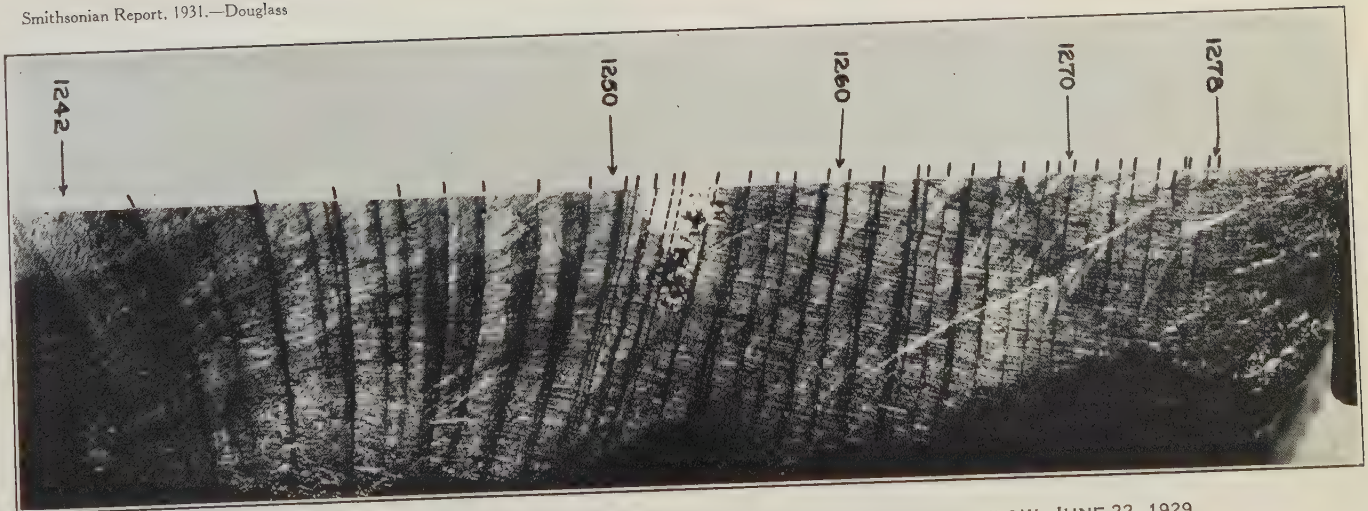
1. Prescott rainfall and tree growth; the lower pair of curves shows the agreement when the tree growth is corrected by a slight conservation formula. 2. Growth of 57 trees in north Europe, and sun-spot numbers. 3. First automatic cyclogram of sun-spot numbers, 1755 to 1910 negative (published in Astrophysical Journal, vol. 41, No. 3, p. 174, April, 1915). 4. Cyclogram of Flagstaff 500-year tree record. A 14-year cycle or its multiple persists through the whole sequence in a horizontal band; in the left one-quarter, 1400 to 1550, the Hellmann relation (5.5 years) may be seen. 5. Summary of cycles found in 305 western trees, compared with simple fractions of the Brückner cycle, here taken as 34 years. (Published in Report of Conferences on Cycles, Carnegie Institution, p. 41, 1929.) 6. The "Hellmann Relation" in Arizona trees. 1410 to 1530. (Climatic Cycles and Tree Growth, vol. 1, p. 102, 1919.)



THE "RINGS THAT CLOSED THE GAP" IN SPECIMEN HH–39, FOUND AT SHOWLOW, JUNE 22, 1929

Double and even triple rings occur between 1242 and 1251, but their annual character as marked may be readily verified on the wood itself which gives finer distinctions in coloring and density than can be reproduced.

1. Kawai-o-ku, general view 1928; broken down walls occupy the entire sky line. It covers 9 acres. This was the first prehistoric ruin to be dated by tree-ring methods; numerous small pieces of wood giving dates near 1468 were discovered above the rocks shown at extreme left of this picture

2. Pueblo Bonito, east end, looking south from the cliffs above. This fine part of the ruin, restored by the National Geographic Society, was largely built between 1050 and 1075 A. D.

DATED RUINS

changing cataclysm, the Pleistocene glaciation. You have diligently pursued for many years your investigations of the traces of this event as they exist in North America. Your researches have involved the careful scrutiny of river valleys of the north and the beds of ancient lakes long dry. They have involved millions of exact measurements on the laminated clays laid down by summer meltings of Pleistocene glaciers. From these researches you have measured the severity of North American glaciation. You have determined the length of the ages which have elapsed since glaciation reached its height. You have found indications of the variations which existed in that distant past in the radiation of the sun.

In recognition of these achievements, the Research Corporation of New York has awarded to you through the Smithsonian Institution a grant of $2,500. In token of this award I now, as chancellor of that Institution, hand you this commemorative medal, and wish for you equal success in your future researches.

LATE-GLACIAL CLAY CHRONOLOGY OF NORTH AMERICA

By Ernst Antevs, *University of Stockholm*

[With 2 plates]

Chronology is the framework of history, its units being the pigeonholes in which events, changes, and conditions may be arranged in actual and consecutive succession. It brings order and gives perspective. Chronology is as vital in geology, the history of the earth, as in human and cultural history.

In geology, time is still essentially a vague conception. Mostly it is only relative; one formation is older than another because it lies beneath or because it contains more primitive forms of life. Frequently, however, time is in a way definite, comprising rough estimates in thousands or millions of years. In a few instances it is absolute, with the year as the unit.

The importance of the time aspect in geology is reflected by the many attempts made to determine it. Especially prominent among the endeavors aiming at absolute age are estimates based on atomic disintegration; on climatic changes combined with astronomical phenomena; on climatic changes alone; on the rate of accumulation of salts and degree of salinity of the ocean and of lakes without outlets; on the rate of deposition, thickness, and extent of organic and inorganic sediments; on rate and amount of erosion by rivers, by lakes, and by the sea; on the rate and amount of weathering and leaching of rocks and soils; on the rate and amount of changes of level of land; on migrations and alterations of floras and faunas; and on sediments in which the year is recorded by lamination. All these methods have their good purposes. Frequently two or more methods serve to date the same beds or the same phenomena and afford a desirable check on one another.

The several sediments recording the year are perhaps most important among the means of dating, but they are rather rare, occurring in any frequency and extent only during widely separated ages of the earth's history. First among these sediments comes the varved glacial clay. "Varve" and "varved" are words of Nordic origin that have been applied to designate the "annual deposit" of a sediment, and "yearly laminated." The striking alternation of light and dark layers in the glacial clay recalls annual rings in a cross section of wood. This similarity caused a Swedish scientist, as early as 1769, to assume that a pair of layers in the clay constituted the deposit of one year. Later, the same conclusion was independently reached by several geologists, next by an American in 1832. Various evidences have been presented to prove that a pair of layers actually represents the year (pl. 1*b*).

The varved glacial clay consists of alternating layers of sand, silt, or coarse clay, light in color, and of fine to extremely minute clay, dark in color. The thickness of the coarse layers varies from a fraction of an inch to several inches. The thickness of the fine-grained layers is normally smaller and varies less. The varved clay was formed in lakes and slightly brackish bays outside melting glaciers and ice sheets. It was formed of mud brought directly from the melting ice. Similar clay is now depositing in lakes fed by glacial brooks, for instance, in Lake Louise in the Canadian Rockies. In winter time the late-glacial lakes evidently froze over.

In summer the temperature of the surface water may have ranged from a little above freezing to about 35° F. It may not have attained 39.2° F., for, owing to the fact that water is densest at this temperature, the entire water mass would then have been of 39.2° and the lake would have had complete circulation, enabling winds to mix suspended mud in all water strata and even to stir up the bottom deposits. If this had been the case, the varved clay, if it could be formed, would show signs of erosion, which it does not do except rarely, when deposited in very shallow water. Furthermore, if the surface water at a distance from the ice sheet had risen to 39.2°, this surface water would have sunk in the main lake body, since it was heavily loaded with mud. At a still greater distance from the ice border, where the water temperature was higher, the mud would have sunk rather quickly, because of the lower viscosity of the water. Transportation of large quantities of mud in glacial lakes for more than 100 miles shows that the mud did not sink quickly. Therefore, the surface water of the glacial lakes may have ranged in temperature during summer from 32° to about 35°; the bulk of the water may have been, both in summer and winter,

at a temperature of 38° to 39.2°; and the water stratification may have been constantly inverse with the coldest water at the top. The icy water coming from the glacier was consequently lighter than the lake water, and, even if discharged at the bottom of the lake, rose to near its surface. In doing so it brought along part of the suspended mud which was quickly distributed by waves and currents, the finer the mud, the farther it was spread (fig. 1).

Having arrived in the upper layers of the lake water, the mud began to separate according to coarseness and to sink, the coarse grains fairly fast, the fine particles at extremely slow rates. Silt grains would settle in a few days or weeks. Coarse clay particles, as well as part of the fine clay, also sank to the bottom during the summer. On the other hand, the bulk, or a great part, of the finest particles still remained in suspension when melting ended with the

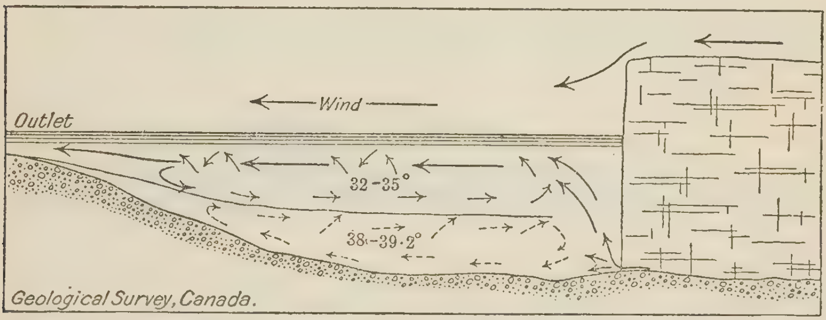


FIGURE 1.—Probable water circulation in a glacial lake, and probable water temperatures, F°., during summer. (From Antevs, Geol. Surv. Canada, Mem. 146, fig. 21.)

arrival of winter. Because of very slow sinking, these minute particles could not reach bottom individually in the course of a year. However, owing to the perfect calm under the ice cover and to the development of a slight salinity of the water as a result of partial dissolution of the silicic acid of the mud, the particles flocculated or aggregated into small lumps, which settled before spring. It is this separation of the grains and particles by their different rate of fall through the water that produced the distinct lamination of the clay, causing the deposition of a silty layer in the summer and a clayey layer in the winter. This pair of layers, representing the annual deposit, is the varve.

The chief conditions of formation of the varved glacial clay were, therefore, that at least part of the fine-grained mud came from a melting glacier, that the water in which deposition took place was fresh, or practically so, and was heavier than the river water, so that this water and the contained mud could rise to the upper strata of the lake and the mud separate and settle according to size of grains and particles.

If these conditions had not been filled, practically all the fine mud would have flocculated and settled during the summer, together with the coarse fractions forming a massive clay. Homogeneous clays were formed where glacial brooks discharged into strongly saline waters, and they are now deposited where ordinary brooks and rivers empty into regular lakes of our latitudes (pl. 1*a*).

If the débris was uniformly distributed in the ice, the quantity of mud brought into a glacial lake during a summer was proportional to the amount of ice melting. The thicknesses of the varves, therefore, record the relative amount of ice melting during the different years. Since ice melting is found, by observations in the Alps and elsewhere, to be determined chiefly by summer temperature, the

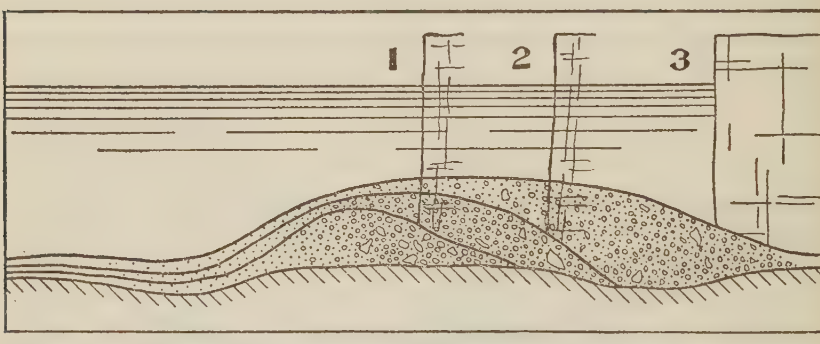


FIGURE 2.—Mode of formation of glaci-fluvial deposits (esker gravel, sand, silt, and varved clay) in fresh water off the receding ice front during three successive years. The bottom varve to the right in the figure is varve number three to the left in the figure. Points to the left were uncovered two years earlier than points to the right. Section through center of glacier orifice. At a distance in lateral direction from the mouth of the glacial river the varve is thin and consists of fine sand, silt, and clay at the very ice edge

relative thickness of the varves was defined, in the last analysis, by the total summer heat. Thick varves, therefore, mean warm and long summers; thin varves, cold and short summers.

While several geologists interpreted the layer-pair in the glacial clay as the annual deposit, Gerard de Geer, of Sweden, went further and, in 1885, propounded a method to use it for a geochronology of the waning stage of the last Pleistocene ice sheets. The method is based on the fact that, when the ice sheet terminated in water, its edge formed the proximal limit of the clay varves. As the ice edge retreated the varves extended farther and farther in centripetal direction. The varves accordingly cover one another as shingles on a roof (fig. 2).

The field operations consist in measuring continuous series of varves in exposures, if possible from the bottom of the clay. The limits of the varves are marked on strips of strong paper giving the

thicknesses (pl. 2). In the office the measurements are transferred into graphs to enable comparison (fig. 3). Because it is determined by the summer heat, the relative thickness of a varve is, under other-

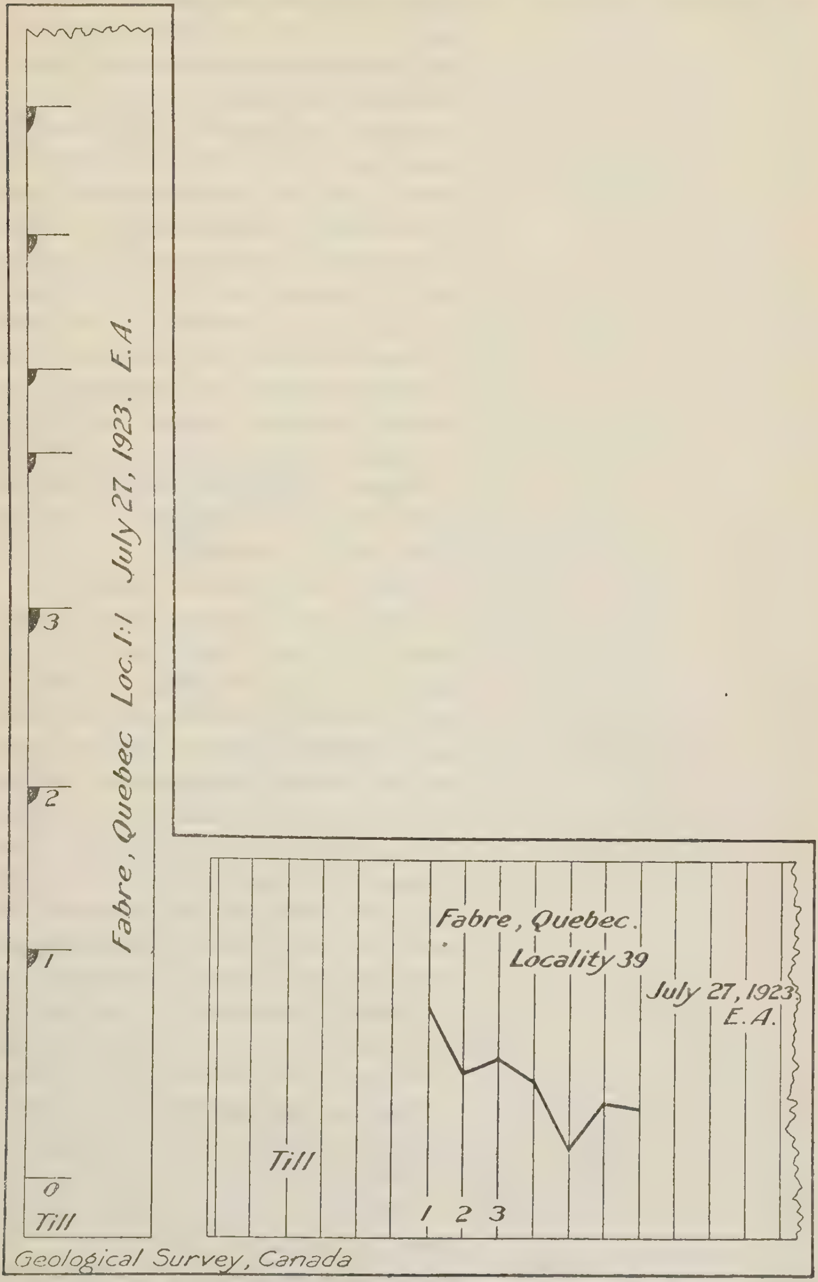


FIGURE 3.—Sample of measurement made in the field and curve constructed from it in the office

wise favorable conditions, about the same everywhere in the area in which the total summer heat underwent similar yearly fluctuations.

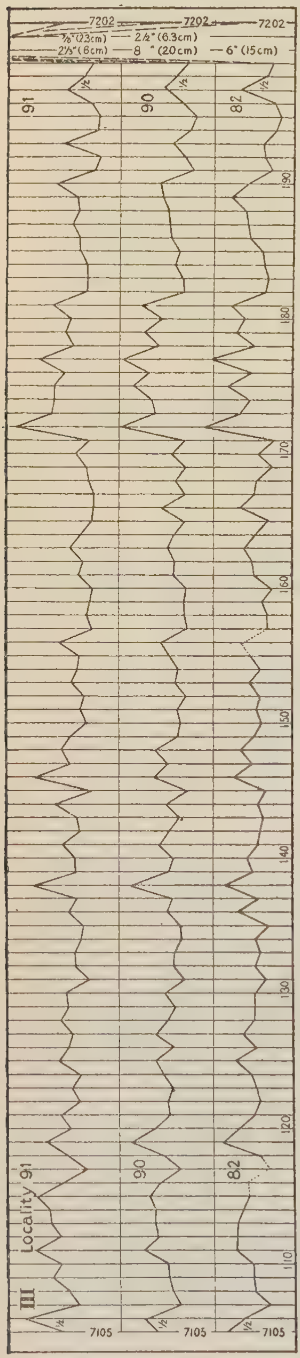


FIGURE 4.—Parts of correlated varve graphs from localities 82, 90, and 91 in the Connecticut Valley. The distance between localities 82 and 90 is 8½ miles; that between localities 90 and 91, 3 miles. (From Antevs, Amer. Geogr. Soc., Research Ser. No. 11, pl. v.)

Varve graphs from the same region, therefore, show essentially the same fluctuations and can be matched, and the separate varves identified (fig. 4). Owing to the imbricated position of the varves, the rate of recession of the ice edge can be determined (fig. 2). Thus, if the bottom varve at one locality is found to correspond to varve number 21 at another locality, the latter place was uncovered 20 years earlier than the former. By a series of varve measurements in the direction of the ice retreat, the rate of uncovering and the time involved can be determined. By measurements distributed over an area the outline of the ice border can be mapped. This is De Geer's method of study.

Graphs of clay varves may be correlated, if they derive from regions that experienced similar yearly variations of the total summer heat and were released from the ice at about the same time. These conditions confine the possibilities of varve correlations within somewhat narrow limits. They preclude correlations of varve graphs from North America and Europe and from distant parts of the same glaciated area. The conditions evidently do not prevent correlations of varve graphs from adjacent valleys, for instance, from the Hudson, the Connecticut, and the Merrimac valleys.

The last ice sheet of North America comprised almost entire Canada and the States down to a line running through New York City, south of the Great Lakes, and a little below the international boundary in the far West. During the retreat of this ice small and

large lakes were dammed between its front and higher land outside. Because the central parts of the ice-covered areas were more deeply depressed by the weight of the ice than the peripheral regions, many lowlands and valleys that now drain southward at that time contained large lakes. The Hudson and the Connecticut Valleys held series of long and deep lakes that extended from the Narrows and from Long Island Sound, respectively, to northern New York and New England. The ocean did not enter these valleys because the sea level of that time stood about 300 feet lower than the present and the coast line probably some 95 miles outside Sandy Hook and 10 to 15 miles outside the east end of Long Island. The Great Lakes were larger in late glacial times than now; the Timiskaming-Abitibi-Timmins region was covered by an enormous water body, Lake Barlow-Ojibway; more than half Manitoba was flooded by the huge Lake Agassiz; and smaller ice lakes existed in all parts of the glaciated area. On the other hand, the St. Lawrence and the Ottawa Valleys were early inundated by a marine gulf, the Champlain Sea, in which, because of the salinity, the fine mud quickly flocculated and settled, forming almost massive clays.

The sedimentation in the glacial lakes was enormous. Lakes that were small in relation to their drainage areas were actually filled with gravel, sand, silt, and clay. This holds for some of the lakes in the New England valleys. Lakes that were ponded by the ice were suddenly lowered or emptied when lower outlets were opened during the withdrawal of the ice front. Other lakes were drained suddenly as a result of overflow and down cutting of their drift barriers. Still other lakes were emptied because of a gradual lowering of their outlets by vertical movements of the land. After the disappearance of the water bodies, the lake beds have been eroded and frequently deeply dissected by rivers. It is exposures of the old lake sediments in river banks, in erosional bluffs on residual lakes, and in clay pits and road cuts that have been used to measure the clay varves (pl. 2).

Thanks to support from the American Geographical Society of New York, the Geological Survey of Canada, Harvard University, the National Research Council in Washington, and other institutions, the writer has been able for several years to study the varved clays in the Eastern States, southern Quebec, central Ontario, the Timiskaming-Cochrane region, and northern Manitoba. The first aim has been to make varve measurements at short interspaces along lines running from the periphery of the ice sheet to its center in Labrador, and, if possible, to connect these separate observations in an unbroken record of the rate of withdrawal of the ice border, of time in years, and of the variations of the total summer heat. The

next purpose has been to correlate geological events with this time scale. The third aim has been to connect, as far as possible, the late-glacial chronology with our Christian era. The fourth aim has been to determine, by means of the varve chronology, the length of time employed for the performance of certain geophysical, chemical, and biological changes, so as to have meters that may help us to estimate the time factor for similar changes and processes when no direct means of determining time is available.

Varve records consequently have been obtained for considerable parts of the age of waning of the North American ice sheet. The length of time that the last ice sheet kept its greatest extent in Long Island is not directly determined, but a comparison of the bulk of the two terminal moraines with that of moraines whose time factor is known suggests that this entire marginal zone represents roughly 2,000 years. The ice sheet began to withdraw almost immediately after reaching its southernmost line. From varve measurements, moraines, and other features the time of release of the belt extending from the terminal moraines to Newburgh, N. Y., and Hartford, Conn., may be estimated at about 5,500 years. The rate of retreat of the ice front has been determined from Hartford northward to St. Johnsbury, Vt., with exception of one narrow zone at Claremont, N. H. Besides the main line of clay measurements in the Connecticut Valley, long controlling lines have been obtained in the Hudson and Merrimac Valleys. The time occupied by the ice recession from Hartford to St. Johnsbury is about 4,100 years. Since the distance is 185 miles, the rate averaged 240 feet a year, or 22 years to a mile. The actual rate of melting back varied considerably. At Northampton-Amherst, Mass., and probably again at Claremont, N. H., the ice border halted and readvanced. At Woodsville, N. H., the recession was as much as 1,100 feet a year, the highest amount observed in North America outside of Manitoba. Shortly after, the recession grew slower, and at St. Johnsbury it came to a stop, followed by a short advance.

The ice border of St. Johnsbury may have trended westward to the Adirondacks and then southwestward to south of Lake Ontario. In the belt extending from this line to North Bay and Mattawa the rate of decay of the ice has not been determined by varve measurements because of scarcity of clays, but the uncovering coincided almost precisely with the life of Lake Algonquin, a very prominent lake occupying the basins of the three upper Great Lakes. The several successive stages constituting Lake Algonquin, the changes of level of the Ottawa region, varve series, and other things, all indicate that the time occupied by the ice release of central Ontario was long, some 10,000 years, in round numbers.

In the belt between Mattawa and Lake Timiskaming varved clay is practically lacking. The ice retreat from the mouth of Montreal River on Lake Timiskaming to La Sarre on the Transcontinental Railway northeast of Lake Abitibi took 1,208 years. Since the distance is 118 miles, this represents an average of 515 feet a year. The rate was relatively uniform in wide belts, though it increased northward. Later it became irregular, and when the ice front had reached far north of Cochrane, it halted and began to move southward. This readvance probably amounted to as much as 70 miles, for the ice border finally reached Iroquois Falls and points 22 miles south of Cochrane. Contemporaneous with the beginning of this readvance the huge Lake Barlow-Ojibway, held in by the ice in the north, was suddenly drained northwestward to Hudson Bay. This event took place during the years 2,022 (or 2,015) to 2,027 after the uncovering of the mouth of Montreal River on Lake Timiskaming. The drainage marks the end of the continuous varve chronology in these regions, for subsequently there were only small, scattered lakes in which varved clay could be deposited. At points farther east, however, it may be possible to extend the varve series toward the ice center in the Labrador peninsula, though this is hardly profitable until the wilderness of this region has become more easily accessible.

In addition to these longer varve records, shorter ones comprising from 100 to about 1,000 years have been obtained in New Jersey, New York, New England, southeastern Quebec, the regions east and north of Lake Huron, and northern Manitoba. Local glacial geology has been correlated with these chronological fragments, which, it is hoped, will ultimately be tied together with the longer varve series.

As touched upon, correlations of varve graphs from North America and Europe are not possible. However, a correlation of the late-glacial epoch in North America and Europe may be made on the basis of the major changes of temperature that are recorded in the rate of disappearance of the ice sheets. The climatic alteration that set a stop to the growth of the ice sheets and introduced their waning was the greatest in late Quaternary time. Since its main factor was a temperature rise, and since marked temperature changes in the post-glacial epoch seem to have made themselves felt both in North America and in Europe, it is more likely than not that the last main ice sheets began to shrink at about the same time. If they did not, the American ice sheet may have been the earlier to commence waning, not vice versa. It is therefore probable that, generally speaking, the peripheral belts of the two main areas of glaciation were uncovered at the same time. In the region between the south side of Lake Ontario and Mattawa River, which forms the

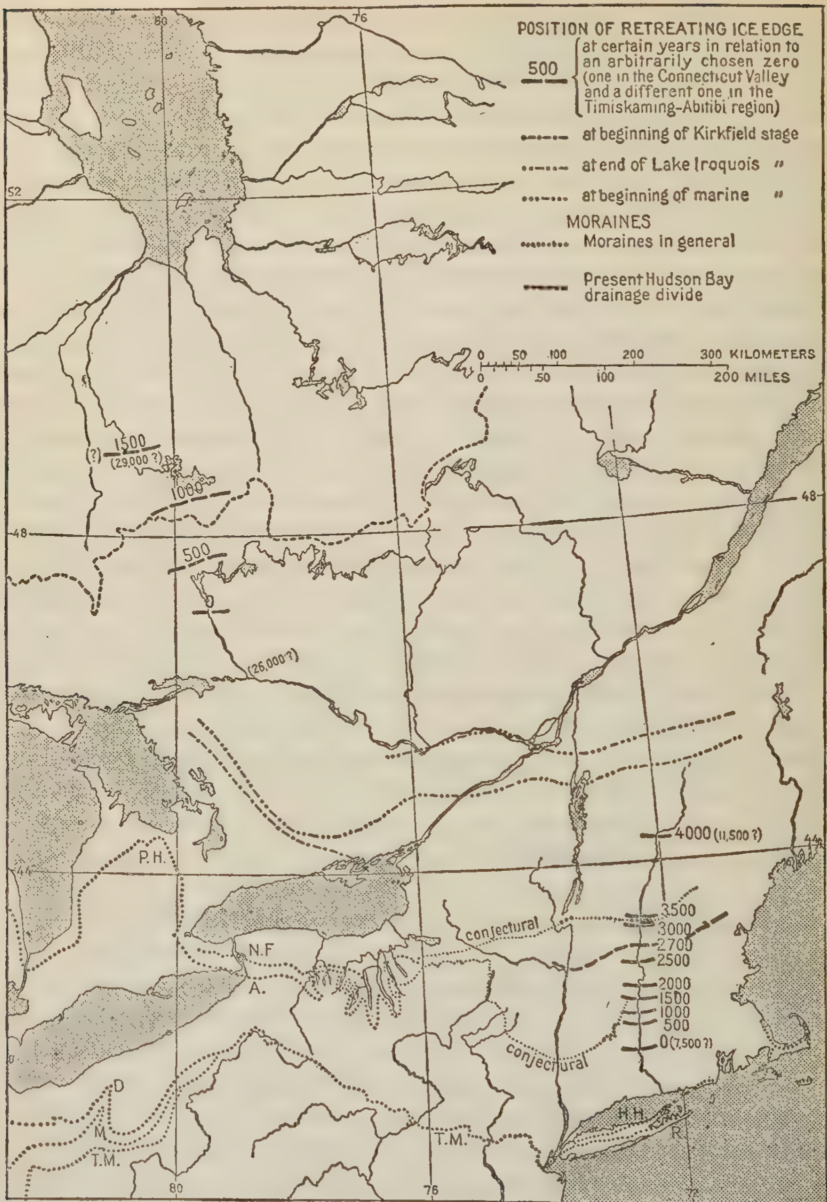


FIGURE 5.—Retreat of the last ice sheet in northeastern North America. (Moraines in the Eastern States from various sources; moraines in the Middle West from Leverett and Taylor, 1915, p. 62; and moraines between the lakes from Taylor, 1924a)

R., Ronkonkoma; H. H., Harbor Hill; T. M., terminal moraine; M., Mississinawa; D., defiance; A., Alden; N. F., Niagara Falls; P. H., Port Huron. The estimates of the time of release of the belt between Lake Ontario and Mattawa River is probably too long. The figure 26,000? at Mattawa and 29,000? at Cochrane should be altered to 21,500? and 24,500?, respectively. The length of time since the ice sheet reached its climax in Long Island is probably 35,000 years, in round figures. (From Antevs, Amer. Geogr. Soc., Research Ser. No. 17, fig. 29)

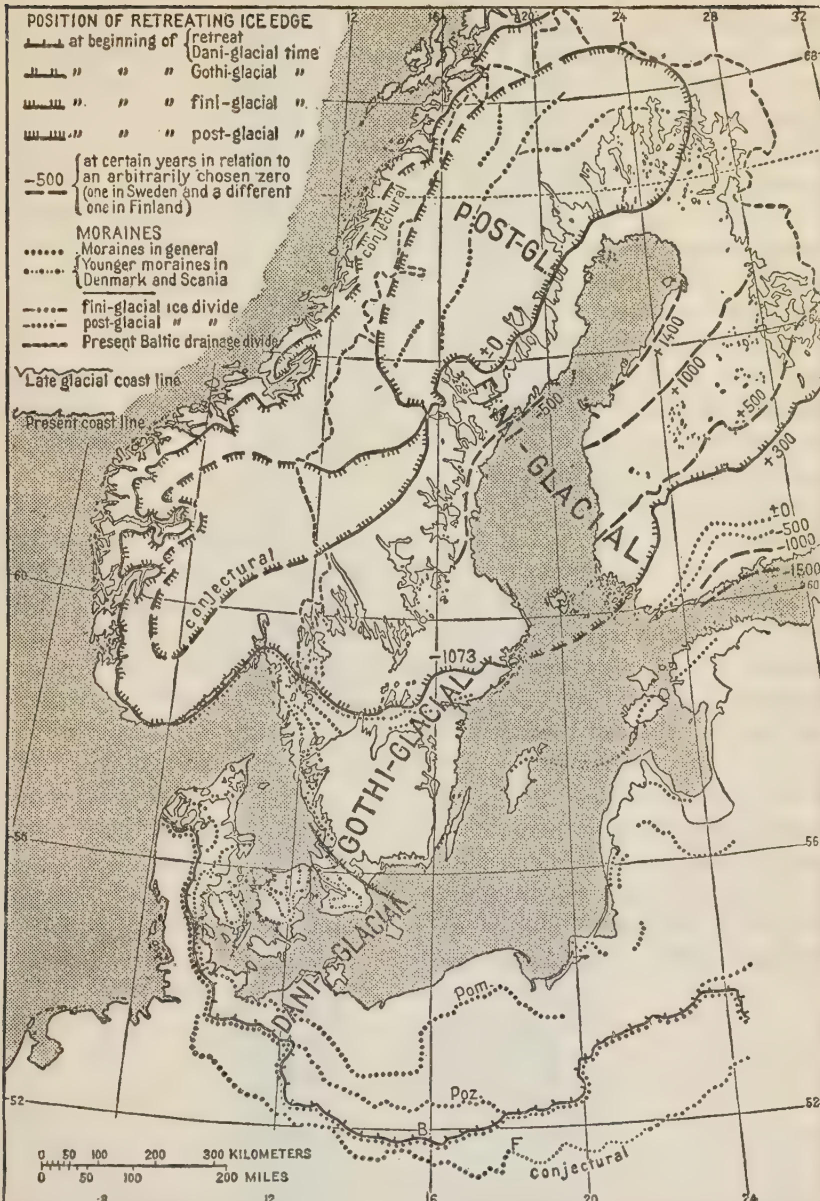


FIGURE 6.—Retreat of the last ice sheet in northern Europe. (Base map and stages in Sweden and Norway after De Geer, 1925. Stages in Finland and correlation with Sweden after Sauramo, 1923 and 1926. Moraines in Denmark after Madsen, 1919, and Milthers, 1922. Moraines in Germany after Woldstedt, 1925a. F., B., Poz., and Pom. designate the Fläming, Brandenburg, Poznań (Frankfurt) and Pommerania moraines.) The peripheral belt or the zone from and including the Brandenburg moraine to but excluding the Pommerania moraine should be designated as Germani-glacial subepoch. The name "fini-glacial" should be substituted by "Fenni-glacial," referring to Finland. (From Antevs, Amer. Geogr. Soc., Research Ser. No. 17, fig. 30)

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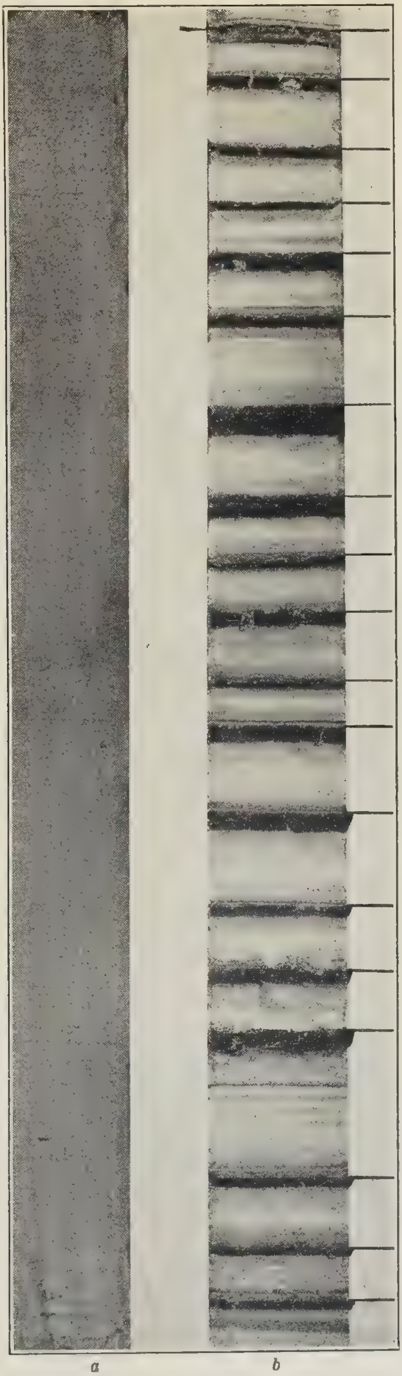
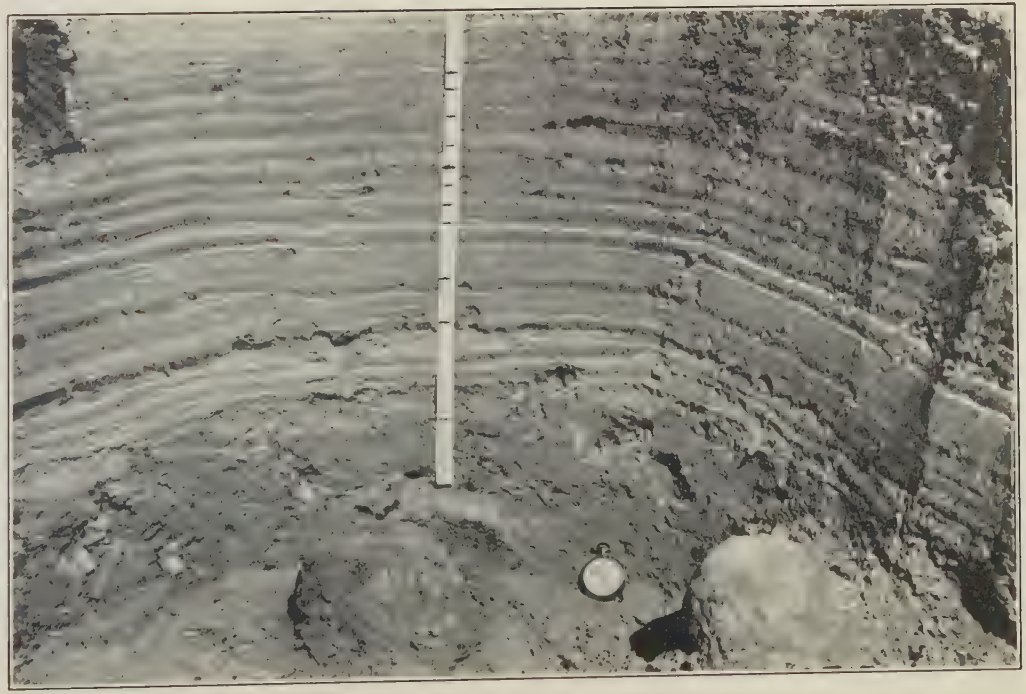
intermediate belt in North America, the uncovering was exceptionally slow. In the Danish Islands, which represent the intermediate zone in Europe, the recession was also slow and repeatedly interrupted by large oscillations. Central Ontario and the Danish Islands may therefore have been uncovered at the same time. In the regions north of these intermediate belts, both in North America and in Europe, the rate of retreat was rapid for a few thousand years. When the ice fronts had retired to the Cochrane region in Ontario and to central Sweden and southern Finland, respectively, they halted and oscillated. Also these stages of recession and halt perhaps correspond, though it is important to note that the oscillations at Cochrane represented a much longer time than did those in Fenno-Scandia which amounted to 659 years. For the present the attempts at trans-Atlantic correlation can hardly be carried beyond these general suggestions.

Because the rate of retreat of the ice front and the thickness of the clay varves form direct measures of the amount of the relative summer heat, they furnish excellent material for the study of long as well as short temperature cycles. However, few analyses for determining cycles have been made. The record of the summer heat supplied by the varved glacial clay is the longest known. The clay chronology, even though incomplete, sheds light on several problems not touched upon in the preceding, as, for instance, the rate of erosion, rate of development of shore lines, rate of sedimentation, rate of leaching and weathering of soils and rocks, rate of vertical movements of the earth's crust resulting from the removal of the ice load, rate of occupancy by plants and animals of the lifeless regions that were exposed with the melting of the ice sheets, rate of development of plant and animal associations, and on the rate of evolution of human species, races, and cultures.



a. Massive postglacial clay from La Sarre, Quebec. Formed by redeposition of varved glacial clay. b. Varved late-glacial clay from Espanola, Ontario. (Actual length of samples 1½ feet.)



VARVES ARE MEASURED IN THE FIELD BY MARKING THEIR LIMITS ON STRIPS OF STRONG PAPER

The varved clay rests on till. Pikwitonei, Hudson Bay Railway, Manitoba.

SHAPING THE EARTH [1]

By William Bowie
U. S. Coast and Geodetic Survey

THE CRUST OF THE EARTH

It is generally recognized that the earth has had a surface of solid material for something like a billion and a half years. At the beginning of this time the earth's surface was irregular and there have been vertical and horizontal changes occurring continuously during this long interval. These changes have been due to erosion and sedimentation and to forces which are acting on the materials forming the outer 50 or 100 miles of the earth.

If the earth's material were in a liquid or highly plastic condition, and if there were no rotation, its surface would be a true sphere. With such a body undergoing rotation the surface would be a spheroid. It has been found by geodetic measurements that the shape of the mean sea-level surface approximates very closely a true spheroid. The deviations between the spheroid and the water surface, or geoid, are probably not greater than 100 meters. These forms are, of course, due to the continuous gravitational attraction of the particles of the earth for each other. The earth's surface is irregular because of the presence of material of different densities near the earth's surface. Under the continents the densities are less than they are for the material under the oceans. There is rigidity in the outer portion of the earth for otherwise there would be a slumping down of the high areas and the moving material would fill up valleys and ocean basins and bring the earth's surface to a true spheroid.

FORMATION OF OCEANS AND CONTINENTS

One of the most interesting problems of geology involves the formation of oceans and continents. Some geologists will say that this is a subject that need not be considered for we may accept oceans

[1] Presidential address delivered before the Washington Academy of Sciences, Jan. 15, 1931. Reprinted by permission, with author's revision, from Journal of the Washington Academy of Sciences, vol. 21, No. 6, Mar. 19, 1931.

and continents as having come into being prior to the present geological age and that our attention should be given to the problem of unfolding the geological record since the beginning of sedimentation. The mind of a human being can not be confined to any particular subject or group of subjects nor to any particular phase of a subject. It is bound to consider any question that presents itself.

It does seem very strange that we should have great masses of material standing above sea level, as continents and islands, and great troughs or basins below the waters of the oceans. We have enough geodetic evidence to prove conclusively that the ocean bottoms are depressed because of the greater density of the material in the crust below them, and that the continental and island masses stand above sea level because the density of the material in the crust below them is less than normal; but what could have caused these abnormal densities? Why is it that under the continents we have a layer, which some claim is about 20 miles in thickness, of light rocks called granites, while under the oceans we have no granites?

There have been many explanations offered as to why we have oceans and continents, but the only one that appeals to me as having decided merit is that advanced by Osmond Fisher. About 40 years ago he wrote a book entitled "Physics of the Earth's Crust," which contains much material of great value. He has a chapter on the possible origin of oceans and continents in which he discusses Darwin's idea that the moon at one time was thrown off from the earth. Darwin's discussion of the birth of the moon was more or less an academic one, and he made no suggestion as to what was the condition of the earth at the time that this birth occurred, but one is led to believe by Darwin's writings that he had in mind a fluid earth. Fisher believed that there was an outer solid shell on the earth at the time that the moon was formed and that the earth lost much of the outer granite shell as a result of the disruption. The places from which the crustal material was thrown off were filled with subcrustal material, but the light granite occupied greater depth than the heavier subcrustal material which replaced it. In consequence the healed scars had surfaces which were lower than the surfaces of the portions of the crustal material which remained.

Darwin's hypothesis is based on the idea that the earth was rotating very rapidly and that as it slowed down to such a rate of rotation as would make the tides, caused by the attraction of the sun, synchronize with the natural period of vibration of the earth, there would be an accumulation of tidal effect which would make the earth's mass unstable. Darwin estimated that at the time of, or just before, the disruption, the major axis of the earth was about twice the length of the minor axis. This would mean that the

earth's surface must have been increased by approximately fifteen millions of square miles. The solid crust, which at the time of the birth of the moon must have been 30 or 40 miles in thickness, could not have stretched over this increased surface but would have been fractured and torn apart with great gaps between the crustal blocks. It may be that this distortion just prior to the birth of the moon had more to do with the scattering of the remaining crustal material over the earth's surface than the actual disruption.

It is rather interesting to look at a globe and note that the two coasts of the Atlantic are so nearly parallel that they remind one of the shores of a great river. Wegener has advanced a theory that North and South America broke away from the rest of the continental masses and moved westward during recent geological times. This is a very interesting theory which has many advocates and also many opponents. I am rather inclined to think that there are difficulties in the Wegener hypothesis which are very hard to explain away. It seems to me that the Fisher idea of the birth of the moon gives us a rather logical explanation of the creation of oceans and continents, and the strongest point of this theory is that it does no violence to isostasy.

It is certain that the earth's surface was irregular at the beginning of the sedimentary age, for without irregularities, such as we now have, the water of the oceans would have covered the whole earth's surface to a depth of approximately 9,000 feet if the amount of water was the same as now. With all of the land area covered by water, there could have been no erosion and sedimentation, such as we have had for a period of approximately one and one-half billions of years.

KNOWN FACTS ABOUT THE EARTH

The earth should be treated like any material structure which comes under our observation for explanation or analysis. No one, of course, can give us the true explanation of how the earth came into being or state accurately what has been going on to change its surface configuration. But we have now at hand a number of facts which should enable us to arrive at some logical conclusions. We know, of course, the earth's shape and size, the portions of its surface covered by land and water, its average density, and the density of its surface material. We also know that the temperature increases with depth. We know that there are many earthquakes occurring annually and that there is no area which is entirely free from them. Most of the quakes are extremely slight, but we are reasonably certain that, with few exceptions, they result from breaking rock and, therefore, there must be forces within the earth large enough to cause such breaking.

We know that there has been a tremendous amount of erosion and sedimentation during the present era, which is called the sedimentary age of the earth. It is certain that the earth's surface was irregular at the time that sedimentary rocks began to be formed, for without an irregular surface there could have been no running water, and without running water there could have been no erosion and sedimentation. Of course, no one knows whether the amount of water on the earth has been constant or variable, but it is reasonably certain that land has been exposed above the waters of the ocean for about a billion and a half years. This is an estimate that is frequently used by students of the earth, and it seems to be generally accepted as of the order of magnitude of the period of time that has elapsed since the formation of the first sedimentary rocks.

Geologists tell us that practically all of the exposed areas of the earth have at some time in the geological past been below sea level. These areas are now at varying distances above sea level and, hence, their change in elevation, with respect to sea level, must have been due to an actual lifting up of land areas rather than a decrease in the amount of water of the earth. If the latter had been the cause for the changes in elevation, there would be uniformity in the elevations of exposed strata.

The isostatic investigations indicate that the solid or rigid material of the earth extends only to a depth of approximately 60 miles below sea level. Some investigators are of the opinion that the depth to which the solid rock extends is very much smaller than that. The interior of the earth acts as if it were plastic to long-continued stresses. The earth has an outer shell which rests upon a plastic interior. A disturbance of the isostatic equilibrium leads to horizontal and vertical changes in the earth's surface. Some areas go down under the weight of sediments and other areas which have been undergoing erosion for long periods of time increase in elevation. There is also a rising up of material that was once below sea level and a sinking down of areas that were once standing high above sea level.

These and other known facts regarding the earth are the basis for the interpretation of the processes which have shaped its surface.

There have been many theories advanced as to why the earth has an irregular surface. Such theories may be considered as mere guesses, for no one can reproduce to-day the forces, resistances, and temperatures that must have been involved when the earth came into being or when its surface was changed from one of fairly uniform elevation to one which has the great differences in elevation that are seen to-day.

Mineralogists tell us that the continents are underlaid by granite, and that granite is absent from the crust under the ocean. Granite

has a smaller density than that of the basalts which underlie the oceans. Originally the earth must have had the granite or light material lying over its surface like a huge blanket of fairly uniform thickness. Why is it that now the granite is absent from such large portions of the earth's surface? There are certainly no known forces that could push the granite up into isolated masses. Gravity would have resisted such piling up, and if forces had been sufficiently great to force the granite into separate masses, these masses of crushed rock would have slumped down soon after the forces had ceased to operate.

ISOSTASY

It was a geologist, the famous C. E. Dutton, of the United States Geological Survey, who coined the word "isostasy" in an address, entitled "On Some of the Major Problems of Physical Geology," at a meeting of the Philosophical Society of Washington, in 1889. Dutton discussed some of the major problems of geology, including, of course, the formation of mountains and the effect of the tremendous amount of erosion and sedimentation. He came to the conclusion that the shifting of material caused stresses which could not be withstood by the strength of the earth's materials. He felt that there must be a sagging down of the earth's surface under the weight of the sediments and a rising up of the surface where erosion had carried material away. He stated that in his opinion mountains are not extra loads added to the earth's crust but that they are due to lighter than normal material in the crust below them. In effect he outlined what might be called a flotation hypothesis, that is, that the continents were floating in heavier material just as ice floats in water. A corollary of this hypothesis of Dutton's is that the irregularities of the earth's surface are due to deviations from normal densities in the outer portion of the earth. Under the oceans the density is greater and under the continents less than normal.

At the beginning of the present century geodesists realized that isostasy was a subject of vital interest to them. Previously, for decades, they had been attempting to explain the abnormal behavior of the plumb line to which astronomical observations are referred and of the pendulum by which values of gravity are determined.

THE FIGURE OF THE EARTH

If the earth's surface had no irregularities but conformed to a mathematical surface (a spheroid of revolution), then at any place on it the direction of gravity would be at right angles to a plane tangent to this spheroid at the point of observation. But the earth has an irregular surface and due to this irregularity the figure

formed by the surfaces of the waters of the ocean and of the waters of sea-level canals (extended, in imagination, through the continents) deviates from a true mathematical figure. This deviation is undoubtedly a maximum under the great mountain systems like the Himalayas and the Alps, where the geoid, or water surface, is above the mathematical one. Conversely, over the deepest parts of the ocean the geoid, or water surface, is probably depressed to the maximum amount below this spheroid. In any event, there is an angle between the water surface and the mathematical surface at any point at which astronomical observations may be made. This angle means a deviation of the direction of gravity, or the plumb line, and affects the observations for astronomical latitudes and longitudes accordingly.

EFFECT OF TOPOGRAPHY ON GEODETIC DATA

Geodesists had noticed this condition in a number of parts of the earth where surveying and mapping operations had been undertaken, and efforts were made to apply a correction for the influence of the irregularities of the surface. It was evident to each investigator that a mountain system, such as the Himalayas, would have an attractive effect on the plumb line at stations within a reasonable distance of it. Efforts were made to compute the effect of these great masses which lie above sea level, but when such corrections were applied it was found that they were larger than were necessary to bring the theoretical and observed values into accord. The mountains, apparently, were lighter than normal, but impossibly small densities would have to be assumed for the materials composing the mountains to bring the two values into exact agreement.

Pratt and Airy, working on geodetic data about the middle of the last century, arrived at the conclusion that the reason why mountains and continents stand above sea level is because lighter materials lie below them. While they did not, so far as I am aware, make any definite statement that the abnormal densities could only extend to a moderate depth, yet this idea was implied in their statements regarding the deficiencies in densities that must lie below mountains and continents. They advanced their ideas about 75 years ago, but it is only within the last 10 years that their ideas and those of Dutton, expressed 41 years ago, have been accepted generally by students of the earth as a working principle in earth studies.

VARIATIONS OF GRAVITY

Geodesists have used geodetic data in the form of triangulation, of astronomical determinations of longitude and latitude, and of

values of gravity to test this flotational hypothesis. It is the only method, so far as I am aware, by which the idea can be quantitatively tested. We have a direct measure of the extent to which the plumb line deviates from the line that is at right angles to the spheroid surface, and a measure of the difference between the theoretical and observed values of gravity. The idea of isostasy can be tested by means of these data.

If the earth were a true spheroid and there were no irregularities on its surface and if the densities along each radius were normal, gravity would increase slightly as one proceeded from the Equator to one of the poles. The attraction of the earth at sea level would be about one two-hundredths part greater at a pole than at the Equator. Enough work has been done to prove conclusively that gravity does follow very definite laws. For instance, it changes on the average about one part in a million for a mile change in latitude. It changes one part in a million for about 10 feet change of elevation. These changes are perfectly normal, for the centrifugal force is a maximum at the Equator and zero at the poles, and, besides, the attraction at either pole is greater than it is at a point on the Equator. Necessarily, too, a particle is attracted less by the mass of the earth when elevated than when it is exactly at sea level.

It is not necessary to go into details regarding the geodetic tests of isostasy, for the methods used and the results obtained have all been set forth in a number of publications of geodetic organizations. It is sufficient to state that when isostasy is taken into account in computing geodetic data, harmonious or practically harmonious results are obtained. By means of geodetic data it has been possible to determine the approximate depth below sea level to which these abnormal densities extend. The most probable depth obtained from mountain and plateau stations of the United States is about 96 kilometers, approximately 60 miles, below sea level. This depth is confirmed by determinations of A. H. Miller, of the Dominion Observatory at Ottawa, Canada, who found, from analysis of gravity data at mountain stations in the western part of that country, a depth also of approximately 60 miles.

COMPARISON OF PRATT AND AIRY HYPOTHESES

There has been much discussion in literature on isostasy of the question as to whether the Pratt or the Airy hypothesis is the true one. Pratt postulated that the densities vary under the different classes of topography. Under the oceans the density would be abnormally great and under the continents it would be abnormally small. Airy, on the other hand, suggested that the depth of com-

pensation is very irregular and that crustal masses under the continents extend much farther below sea level than do such masses under the oceans. Under mountain areas these protuberances would be greater than under plateaus and valleys.

We have not yet been able to prove which of the two hypotheses is the true one, since the application of either of them to gravity and deflection data gives about the same satisfactory results. However, looking at the matter from a purely physical standpoint, I am inclined to think that there are decided weaknesses in the Airy hypothesis and that the Pratt hypothesis is probably the true one. Perhaps with a greater accumulation of data we may in the future be able to show which one of these hypotheses is the better one. We should be able to derive a depth of compensation for each extensive mountain area and if the Airy hypothesis is the true one, then the higher the mountain area the greater should be the derived depth of compensation. When such mountain areas as the Andes and the Himalayas are covered by geodetic stations, it should be possible to make this test.

ASSUMPTIONS UNDERLYING ISOSTATIC INVESTIGATIONS

Necessarily, in carrying on such investigations as have been involved in the tests of isostasy, assumptions have to be made. The assumptions made by geodesists are approximately as follows: First, that isostasy is complete or perfect for even quite limited portions of the earth's crust; second, that there is a uniform distribution with respect to depth of the compensating deficiencies of density under continents and of the excesses of densities under oceans, that is, that the compensation starts at sea level and extends uniformly about 60 miles to the lower limit of the crust; third, that the compensation is directly under the topographic feature and not spread out horizontally with respect to that feature; and fourth, that the density of the rock above sea level is 2.67.

These assumptions are made merely for the convenience of the investigator. It would be practically impossible for him to assume anything but very simple conditions because of the very large amount of work involved in making the computations required for the tests. We do find that, when these assumptions are made and corresponding corrections are computed, the theoretical and actual values for the astronomical longitudes and latitudes and for values of gravity are brought very closely into agreement. There are some outstanding differences, and these must be a measure of the degree to which one or more of the assumed conditions are not true. The lower limit of compensation may not be a regular surface, it may be very much deeper under some parts of the continent than under others, and it

may be deeper under the continents than under the oceans. The compensating deficiency of density under a mountain system may be confined to a rather narrow zone vertically and not extend throughout the thickness of the crust. The compensation may be distributed widely in a horizontal direction from the topographic feature, and deficient densities under land masses and excessive densities under ocean areas may not be sufficient to balance the irregularities of the earth's surface in the regions studied. Finally, the density of surface rock is variable. Undoubtedly, all of these factors come in to cause the differences between the theoretical and actual values which we call anomalies, but the anomalies are so small after the isostatic method has been applied that investigators are inclined to believe that the principle of isostasy has been amply tested and proved. Some of them, and I am one, believe that the principal cause of the anomalies is the effect of abnormally heavy or light material near the earth's surface and close to the astronomical or gravity stations. If we could find out the actual distribution of density in the earth's materials for a depth of 5 or 10 miles below the earth's surface, I am confident that we could reduce nearly all of the anomalies.

This brings up the question as to whether or not it would be possible to discover what the geologists call structural features that are buried below the earth's surface. This is a matter of great importance and may have a bearing on the search for petroleum and ores. The gravity survey conducted over this country indicates certain places where there are extra heavy or extra light masses of material fairly close to the earth's surface. I do not know of any oil having been found, or drilling for oil having been undertaken, near any of our gravity stations as a result of our data, but I am sure that an intensive gravity survey would disclose structure that might be of value in the oil and mining industries.

SOME ISOSTATIC CONCLUSIONS

The evidence seems to justify the conclusion that all mountain and plateau areas were at one time occupied by low lying portions of the earth's surface on which great beds of sediments were laid down. Then these areas were raised up to form either mountains or plateaus. If there was much distortion, mountains resulted, and if the area went up in a more or less uniform way, extensive plateaus were formed. What caused these uplifts is one of the outstanding problems of the science of geology. Many of the investigators of the past have postulated horizontal thrusts, while some, Dutton included, were inclined to favor a vertical movement as the predominant one with horizontal movements as incidental.

It is absolutely certain that the masses pushed up, whether by vertical or horizontal forces, are not extra loads above the surface which limits the depth of isostatic compensation. These masses above sea level are, of course, extra loads on the sea-level surface, but they can not be extra loads on the imaginary blocks of the earth's crust which are resting on the plastic subcrustal material. If they were extra loads, this fact would be easily and clearly indicated by geodetic data in the form of deflections of the vertical and values of gravity. The masses that appear above sea level are compensated for by the deficiency of density in the material lying below them.

The zone within which the compensation of topographic features lies must be of limited depth. If it were otherwise, the computed effect of the compensation would be practically zero and the material above sea level would have full effect on the direction and force of gravity.

It has been concluded from a study of the deflection data for the United States that the actual deflections of the vertical are on the average not more than about 10 per cent of what they would be if the masses above sea level and the deficiency of the mass in the oceans were not compensated by deviations from normal densities in the crust below. This is the very strongest evidence possible in favor of isostasy and, also, in favor of the theory that the outer portion of the earth is rigid and strong. This rigid material, which has been found by geodesists to extend to an average depth of approximately 60 miles, will resist for extremely long times gravitational forces which tend to make the earth's surface a true spheroid. The gravity data supplement the data derived from the deflection of the vertical in showing the existence of isostasy.

Since areas of sedimentation and erosion and all plateau and mountain regions are now in isostatic equilibrium, it seems reasonably certain that they have been in equilibrium throughout the geological era. If this is true, we must conclude that there has been an actual uplift of the surface in some places and a down-warping in others. These changes in the earth's surface can occur only by vertical movements, due to changes in the density of the crustal or subcrustal material, or to the action of horizontal forces. I am inclined to favor the former idea because it is rather difficult to see where horizontal forces of sufficient magnitude could originate. Since the sea-level surface of the earth is at all places at right angles to the direction of gravity, it is difficult to see how any large horizontal component of the gravitational force could come into existence.

I believe that there has been no collapsing of the outer shell of the earth on a shrinking nucleus. The outer solid shell of the earth must be of the magnitude of 60 miles in thickness, and certainly at

such a depth as 60 miles there could be no voids; the outer shell, or crust, of the earth must be in intimate contact with subcrustal material and, therefore, there is no opportunity for the crustal material to collapse on a shrinking interior. Should the interior of the earth be losing heat and contracting in consequence, and should the crust of the earth not be losing heat and, therefore, remaining constant in volume, it is probable that the crust merely thickens locally as the nucleus contracts. Any changes in the volume of the nuclear material would be so exceedingly slow that the crustal material would yield locally and the crust would continue to be in contact with the nucleus around the whole earth.

ISOSTATIC ADJUSTMENTS AND EARTHQUAKES

If we accept the principle of isostasy—and it is a perfectly logical thing to do—then we are confronted with the problem of how to apply this principle in geological studies and investigations. It is especially important to apply the isostatic principle to the question of earthquakes.

Earthquakes have been occurring for a billion years, more or less, and probably they will continue to occur as long as the earth has sunshine and rain. An earthquake is caused by the breaking of the outer portion of the earth's material. Without the break there would be no elastic shock. Where the material of the earth is hard, brittle, and elastic, it will resist deformation due to a force acting on it until the stress is greater than its strength and there will be a sudden yielding in the form of a rupture. Any elastic substance necessarily has vibrations when it is struck or broken, and that is exactly what happens to the earth when we have an earthquake. The rock is snapped or broken, and the elastic waves set up by the sudden rupture travel great distances.

Records of earthquake waves are made with an apparatus called a seismograph. There are many of these instruments scattered over the earth's surface and the number of earthquakes annually recorded on them has been recently estimated at 8,000. There are many quakes of such small intensity that their shocks are not received at the existing seismological stations. It is impossible to state how many earthquakes actually occur over the earth, but if I might make a guess, I would say from 30,000 to 40,000 a year.

One of the implications from the proof of isostasy is that the outer portion of the earth is much stronger than the materials that lie somewhat farther down. In order that the irregular surface of the earth may be maintained against the tremendous weight of masses of rock above sea level, this outer portion of the earth must be strong, that is, it must have a strength sufficient to prevent the continental

masses slumping down and flowing into the ocean areas to fill up the basins. This strong material extends, according to geodesists, approximately 60 miles below sea level. Below that the material must be lacking in strength and rigidity. It must yield to forces without breaking. As great masses of material are moved over the earth's surface the balance of the crust is disturbed. The extra load caused by sediments must push down the crust beneath and this must force the subcrystal material to move sidewise and some of it to push up the crust from where the eroded material came. The earth's crust is like a sheet of ice on a pond or on the Arctic Ocean. The crust lies quietly on the interior part of the earth until something happens to disturb the equilibrium. Although the crust of the earth is composed of strong material, the strength is finite, surely not great enough to withstand the weight of the tremendous loads that have been shifted on the earth's surface. It is, however, strong enough to maintain the irregular surface of the earth just because of the floating principle.

Earthquakes have occurred probably in all parts of the earth. One can not make an accurate estimate of the maximum size of the portion of the earth's crust in which, throughout geological time, no earthquakes have originated, but we see all about us evidences of uplift or subsidence of the earth's surface. Each continent has above sea level much sedimentary rock that must have been formed below tidal waters. These rocks in many cases are much tilted, curved, broken, and crushed. It is reasonably certain that there has been an uplift of the earth's surface rather than a decrease in the amount of ocean waters to cause these exposures. The best evidence that they have been pushed up is the fact that strata laid down in salt water in horizontal positions are now tilted at various angles from the horizontal. Then again, the same strata exposed in a number of widely separated places are found at different elevations above sea level. This, it seems, is an indication that there has been an actual uplift of the earth's surface. Every one who has engaged in mining operations knows of the tremendous amount of faulting that has occurred in the rocks. A coal seam will be followed for a certain distance and then it gives out. Later the same seam of coal may be found at a higher or lower elevation. The many fractures that are found in mines and at the earth's surface lead one to the very definite conclusion that there has been much shifting of material in the geological past. Each one of these shifts, or changes, where a fracture has occurred, has probably caused an earthquake.

The earth may be classified as a yielding body. It should not be classed as a failing structure. A soapbubble or a glass ball, when subjected to stresses greater than its strength, will collapse, but it is

impossible for the earth to collapse. The earth is like a solid rubber ball which will yield and change its shape to forces that are exerted upon it. The earth is a globe almost spherical, approximately 8,000 miles in diameter. The number of cubic miles of material in the earth is great, but this large globe yields in a surprisingly easy manner to the forces that are acting upon it.

OBJECTIONS TO THE CONTRACTION HYPOTHESIS

Geologists and other students of the earth have for generations sought for the forces which may have disturbed the earth. Many ideas have been advanced and some of them have had wide acceptance. One of these is that the earth's interior is losing heat rather rapidly, while the outer portion of the earth, the crust, is maintaining its temperature. In consequence, there is a shrinkage of the interior of the earth and a collapse of the crust, which causes earthquakes and elevates mountains and plateaus. This process is also held by some to be the cause of oceans and continents. It seems to me that a careful analysis of this hypothesis will lead one to the conclusion that it can not be true. The earth has been likened to an apple or potato. Every one knows that a baked potato or a baked apple has wrinkles in its skin. The contraction hypothesis implies that the nucleus of the earth is like the interior of the apple or potato and that the crust of the earth is like the skin, but the skins of the apple and potato have practically no weight, and, therefore, during the cooking the shrinkage of the interior, due to loss of moisture, makes the skin wrinkle to fit the reduced size of the interior of the apple or potato.

The crust of the earth certainly can not be likened to the skin of the apple or potato. In the first place, the crust is about 60 miles in thickness and is composed of heavy rock. Then, again, this material is so heavy that no wrinkles could possibly form which would have voids under them like the voids under the wrinkles of the apple and potato. There can be no such thing as a buckling or crumpling of the earth's crust on a shrinking interior. If the interior of the earth is losing heat, while the crust of the earth is maintaining its temperature, the loss of this heat must be so exceedingly slow that there can be no chance for stresses to accumulate to such an extent as to cause great horizontal forces. I believe that if in the course of geological time, measured by hundreds of millions of years, the earth's interior should cool and contract, the crust would continue to be in contact with the interior and, therefore, the crust would merely be thickened rather than buckled into ridges and troughs. Much has been written against the contraction hypothesis, notably by Mellard Reade and Alfred Wegener.

DIASTROPHIC FORCES

There are no known forces which have their origin outside of the earth's material which can exert horizontal stresses on the crustal material of the earth of such strength as to form mountains and plateaus and cause earthquakes. It is true that the attractive forces of the sun and moon are exerted on the earth, and, since the portion of the earth that is nearest to the sun or the moon is attracted more than the material that is farther away, a stress is set up. This stress is not of sufficient magnitude, however, to rupture the material or to make it move out of its normal place, except to the extent of a slight elastic deformation called the earth tide. These tide-producing forces of the sun and the moon change phase every few hours as the earth turns on its axis.

I think we can eliminate the attractive effect of the sun and the moon as being the cause of any geological phenomena involved in mountain forming, earthquakes, etc. Of course, the time of an earthquake on an island or near the continental coast may be decided by an exceptionally high or low water tide in the vicinity, but it is reasonably certain that the crustal material is brought nearly to the breaking point by some other cause and that the high or low tide supplies merely the small increment required to increase the stress beyond the breaking strength of the rock. The real causes of the major features of diastrophism must lie within the earth itself.

Much has been written in recent years about the effect of the heat resulting from radioactivity of certain minerals in the outer portion of the earth. This, it seems to me, may be a factor in earth movements, but I am inclined to think it is one of minor importance. In the first place, the radioactivity is largely confined to the granitic material which is supposed to be only from 15 to 20 miles in thickness under the continents. There is no granite under the oceans, but some of the strongest earthquakes occur there and much of the ocean bottom is quite active from a geological standpoint. Broken ground with very steep slopes is found under the oceans, and many oceanic islands are due to volcanic activity. All of this implies that movements are going on in the crust under the oceans, and these surely can not be due alone to the radioactivity of minerals. The basalts which are supposed to underlie the granites of the continental areas and to form the bottoms of the oceans have present in them some radioactive minerals but not in such large proportions as are present in the granites.

Again, we have the problem of accounting for physical or chemical activity that probably occurs even to the depth of 60 miles below sea level. Earth students, who have been writing on radioactive

minerals and their effect on geological processes, are inclined to the opinion that the deep-lying materials have practically no effect on surface changes.

If we eliminate forces existing outside of the earth, forces due to the supposed contraction of the earth's nucleus and the collapsing of the crust, and forces due to the effect of radioactive minerals as major causes of earth movements, we must search for some other forces that might be effective.

We know that the temperature of the earth increases with depth. For the first 2 miles or less we have definite data from the determinations of temperatures in wells. There is a great variation in the rate at which the temperature increases with depth, but a fair average is 50° C. per mile. The temperature certainly continues to increase below the 2-mile depth, for we have many active volcanoes in the world which emit cinders and lavas having temperatures of 1,000° C. or more. Such temperatures would be found at a depth of approximately 20 miles if the temperature gradient were about the same throughout that depth as it is near the surface. Whether the temperature keeps on increasing with depth down to the center of the earth, we can not tell, for there is no way to discover, even approximately, what the temperature may be at great depths. A material may be at a temperature which at the surface would be its melting point or even its boiling point, yet it probably would act like a strong solid when confined by the great pressures which must exist at considerable depths. A very hot interior of the earth, if there is little change in temperature from one period of time to another, will not exert any decided influence on the configuration of the earth's surface. Change in heat, however, whether a decrease or increase, will exert force. It will cause expansion or contraction of materials, but the heat of the interior of the earth is changing so slowly that it can not be a major cause of surface changes. One would be most unwise to assert that the heat of the interior of the earth, without any other influences acting, could not cause changes in elevation and geographic positions of points on the earth's surface, but, if this interior heat is a primary cause of surface movements, no one, so far as I am aware, has given a very clear explanation as to how the changes are effected. I am rather inclined to think that we may eliminate the heat of the earth's interior as the major cause of geological phenomena. This heat does affect those portions of the crust which are lowered by sedimentation or raised by erosion, but it is not the primary cause of surface movements. I believe we should look for something that is closer at hand and easier of understanding.

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EROSION AND SEDIMENTATION

There is one process continuously active which is so simple that apparently its influence on surface phenomena has been ignored or even overlooked except by a few. This is the phenomenon of erosion. Vast quantities of water fall to the earth each year and presumbably this has been going on continuously since the beginning of the sedimentary age of the earth, the one that we are now in. According to the best geological and geophysical evidence, the earliest sedimentary rocks were formed about a billion and a half years ago. It is absolutely impossible for sedimentary rocks to be formed without running water, and to have running water there must be sloping ground. A succession of sedimentary rocks has been formed during the past billion and a half years and for hundreds of millions of years there have been living creatures on the earth, so it seems perfectly logical to assume that rainfall must have occurred during all of that period.

The average rainfall per year over the land surface of the earth is about 30 inches. Of course, there are regions where the rainfall is 100 inches or more, but these areas are very restricted in size, and there are other areas, such as the great deserts, where there is no rain at all or only a very few inches. A rainfall of 30 inches a year amounts to about 1 mile in every 2,000 years, and during the whole of the sedimentary age about 750,000 miles of rain could have fallen. This, of course, means that by evaporation and precipitation the ocean waters have been used over and over again. As the water of the ocean is evaporated, the mineral content remains in the ocean. When the water runs from the continental or island areas into the oceans it carries in suspension or solution some solid material. The solids are mostly in the form of salts. The mineral content of the ocean waters that we now observe has been caused by this process of evaporation and precipitation throughout the sedimentary age.

This transfer of water from the oceans to the continents and then back into the oceans would be of no consequence from a geological standpoint if it were not for the resulting erosion of the exposed surface of the earth. Much of the water runs directly to streams and rivers and eventually reaches tidal water, except in a few desert basins where the rivers have no outlet to the sea, but these latter are very unimportant. The water that runs to the sea carries much material in suspension. The earth's surface is undergoing disintegration as the result of frost and chemical action. As soon as a particle is loosened from a rock, it is subject to transportation to some other place by wind or water. The effect of water in transporting material is believed to be far greater than that of wind. In any event tremendous amounts of material in suspension are carried by water

to the streams and rivers. Another large part of the water that falls to the earth soaks into the ground and absorbs a certain amount of the mineral matter from the rocks. This water seeping through the rocks will eventually reach streams and rivers and then will flow to tidal waters carrying vast quantities of solid material with it. The combination of the material in suspension and in solution results in a large amount of continental matter that is transferred to sea areas each year.

It has been estimated that in the United States the rate of erosion is approximately 1 foot in 9,000 years. Some areas, of course, have very much more rapid rates of erosion than others, but this is the average rate at which material is carried from the area of the United States as a whole to tidal waters. The rate of erosion for the other continental areas is probably just about the same as for our country. This may not seem to be a very rapid rate, for during historic times it would amount to only about one-half of a foot. The average elevation of the United States is about 2,000 feet, and so to erode all of the material lying above sea level would require something like 4,000 times the total length of the historic period.

At this rate, however, something like 30 miles of erosion could have occurred during the sedimentary age. Of course, there has been no such amount of erosion as that. A particular exposed area that is undergoing erosion is worn down to sea level eventually and then erosion ceases, but it is rather remarkable that many areas which have been eroded down to sea level have in a later period been raised up again and thus other material has been subjected to erosion.

It seems probable that the average elevation of the continental areas has never been very much higher or lower than now. I believe that if there has been any change, the average elevation has been getting gradually lower. This is because the continental matter carried to tidal waters is less dense than the subcrustal matter which moves toward the continents to restore equilibrium. The average elevation for all of the continental and island areas of the world is slightly more than 2,000 feet, less than one-half mile, but there are some parts of the earth where the elevations are 3 or 4 miles or more. The maximum elevation of the Himalayan Mountains is more than 29,000 feet, and there are mountain peaks in South America and Alaska which are 20,000 feet or more in elevation. There are great plateaus which stand more than 2 miles above sea level. But these great elevations are offset by vast areas on continents and islands which are only slightly above sea level. The ocean basins have an average depth of approximately 10,000 feet. It seems reasonably certain that some of these areas have changed their depths during the sedimentary age. Some parts of the ocean bottoms have

come up, while others have gone down, but I am of the opinion that the average difference in elevation of the ocean beds and of the continents, now about 2½ miles, has not been much less than it is now at any time during the sedimentary period.

We can now, I believe, get an idea as to where some of the force originates which changes the configuration of the earth's surface. The water falling as rain carries off vast quantities of material in suspension and solution. It unloads certain portions of the earth's crust and overloads others. Some geologists have told us that as much as 30,000 feet, about 6 miles, of material have been eroded from some mountain areas. Then there are other areas on which as much as 40,000 feet, or nearly 8 miles, of sediments have been placed. The earth's materials are not strong enough to resist yielding under these great negative and positive loads. There is a bending down of the crust under the sediments and a deflection upward of the crust under the areas which have undergone great erosion.

The movement of material within the first 5 or 10 miles resulting from the loading and unloading by erosion and sedimentation is not a simple one. We do not have merely a slab of material which can break or bend, but a shell approximately 60 miles in thickness completely encircling the earth. Any distortion or change in one part of this shell would have an effect on all other parts of it if the earth's crust were of tremendous strength, but such is not the case. The crust must yield under comparatively small amounts of sedimentation and erosion. If this were not true, the geodetic data would certainly enable us to detect without difficulty the extent of the masses involved. An extra load of 1,000 feet of material over the Rocky Mountain area would show up at once in the gravity data. The absence of any large differences from normal conditions leads us to believe that there is surely no excess or deficiency of material for the whole Rocky Mountain region equivalent to a blanket 1,000 feet in thickness. A blanket of even 500 feet of material is greater than can be present as an undetected excess or deficient load for an extensive area. We therefore may conclude, I believe, that a blanket of surface rock 500 feet in thickness over a large surface area exerts a force that is great enough to make the crust beneath yield. This yielding at times is so slow that the rocks will merely be bent and deformed, and at other times it is so rapid as to cause rocks to break.

THERMAL CHANGES IN CRUST

Isostasy is a condition of rest. When the materials of the earth's surface are carried in great amounts from one area to another during

the process of erosion and sedimentation, the isostatic balance is disturbed. It is then that gravity comes into play and causes the subcrustal material to move horizontally to restore the balance. We have evidence to show that as much as 6 or 8 miles of sediments have been deposited in the areas along the shores of an inland sea or the margin of an ocean. This load of material pushed the crust down into hotter regions. Each particle of crustal material reached a position several miles below the one it formerly occupied. The geoisotherms were depressed with the crustal material. Eventually, probably millions of years after the cessation of the sedimentation, the geoisotherms returned to their normal positions. In doing so, the crustal material which had been depressed increased in temperature, perhaps as much as 400° C. in extreme cases.

This increase in temperature, of course, expanded all of the crust below the sediments. The expansion tended to be cubical, that is, in all directions, but the material involved was restrained from movement except in the upward direction; hence, the result of the expansion was an uplift of the earth's surface. The amount of movement could not have been sufficient to form great mountain masses rising 2 or more miles high, but is it not possible that certain chemical or physical changes, other than normal expansion took place in the crustal material and that this independent expansion gave the added height to the uplifted surface? This idea is in complete harmony with isostasy and I believe it has much merit.

When an area is undergoing erosion, it is not lowered at a rate comparable with the rate of erosion. If a thousand feet of material is eroded from a mountain area, the crust below will move upward by the influx of subcrustal material which restores the equilibrium. The crust will presumably rise up 800 or 900 feet as a result of the 1,000 feet of material taken from the surface. If a mountain area has an average elevation of about 2 miles, from 5 to 10 miles of material, or even more, will have to be eroded away, if erosion is the only acting agent, before the area is brought to a low level where erosion practically ceases. During this process every cubic yard of material in the crust below the erosion area will have been brought upward 5 or 10 miles or more into colder regions. Eventually the geoisotherms, which have been deflected upward, will resume their normal positions, and in consequence each particle of the uplifted crust will become colder by several hundred degrees centigrade. This causes contraction and the surface becomes depressed. The surface may be depressed even below sea level, in which case new material in the form of sediments will be deposited in the trough or basin that is formed. There is evidence that mountain areas have been elevated and depressed several times and the explanation

outlined above would seem to show how this oscillation can take place.

We have seen from the above analysis what forces are being exerted on the materials of the earth. The movement downward of the crust under the sediments causes a movement of subcrustal material back toward the region from which the sediments were derived. The horizontal movement to restore the balance must occur below and not within the crust. What the effect is of this horizontal movement of subcrustal material on the surface configuration of the earth between the areas of erosion and sedimentation we do not know. Some think that perhaps much of the wrinkling of the earth's surface is due to this subcrustal flow. I am inclined to think that the movement of subcrustal material is so small in extent that there can be little effect of it on the surface above the crust about 60 miles in thickness. I do not think there is anything like a river of material flowing from the region below the sedimentary area to the erosion area. It is more likely that the moving material involves a large volume, and any portion moves only a very short distance. I believe that this movement of subcrustal material, which is a part of the isostatic adjustment, exerts only a minor influence on those portions of the surface of the earth that lie between the areas of sedimentation and erosion.

From the above reasoning there appear to be four definite causes of changes in the elevation of surface areas aside from the direct effects of erosion and sedimentation: First, the depression of the crustal material under an area of sedimentation; second, the moving upward of crustal material to restore the balance under an area of erosion; third, the expansion of crustal material which has been depressed by great loads of sediments; fourth, the contraction of the earth's crust and the sinking of the surface under an area of erosion. These must be the causes of many of the earthquakes of the world, although it would not be safe to assert that these are the only causes of earthquakes and surface movements.

Many geologists do not give as much weight as I do to effects of sedimentation and erosion on changes in the configuration of the earth's surface. Prof. C. K. Leith, in his splendid book entitled, "Structural Geology," published in 1923, tells us that isostasy and the maintenance of isostatic equilibrium are minor causes of structural changes. He expresses his views as follows:

> So far as it is possible to generalize from this vague state of knowledge, it may be said that geologists are at present inclined to give principal place to changing rate of rotation and to the shrinkage of the earth, due to heat transfer from the interior outward, whether they go back to the nebular or planetesimal hypothesis of the origin of the earth; that metamorphism and chemical changes, vulcanism, and forces tending to maintain isostatic equilibrium are regarded as subordinate or contributory causes, or perhaps as special and local expressions of the more basic causes first indicated.

Leith advises the student of the earth to be cautious in any acceptance of a simple and definite explanation as to the causes of structural changes near the earth's surface. He claims that "The problem includes so many unmeasured and perhaps immeasurable factors that no living scientist can claim even an approximately correct perspective; all are groping for the light."

I agree with Doctor Leith that the problem involved in untangling the geological record is a very complicated one, but I do not think it is wise to advise a student to avoid a simple explanation of some phenomena if other explanations are not available, or if the others are so complicated as to leave one mystified and confused. I believe that the only way to attack any scientific problem is to follow a lead, no matter how simple, until evidence may show that one is not traveling in the right direction.

CONCLUSION

Isostasy is now widely recognized as a scientific principle. Its advocates hold that there is a maintenance of the isostatic equilibrium as materials are moved from one place to another over the earth's surface. These are the physical facts which are related to the processes involved in changes in the earth's surface. They have been proven by actual physical measurements. It has been stated that there are great horizontal movements in mountain areas, but that isostasy and its maintenance call for only vertical movements. My answer to this is that I recognize the horizontal movements in mountain areas, but believe that these horizontal movements are incidental to the vertical movements which are involved in maintaining the isostatic balance and which also result from the changes in the temperature of crustal matter brought about by the maintenance of equilibrium. There is an abundance of space in a mountain area for horizontal movements to occur, and it seems to me that it is easier to explain these movements as resulting from upward or downward moving material than as resulting from a shrinking interior of the earth and a collapsing crust.

Isostasy is a geological problem. It was outlined by the great geologist, C. E. Dutton. It has been used by the geodesists merely as an effective means by which to harmonize theoretical and observed values of geodetic data. The geodesists hope that isostasy may prove of great value to geologists in their efforts to write the geological history of the earth.

THE EARTH BENEATH IN THE LIGHT OF MODERN SEISMOLOGY [1]

By Ernest A. Hodgson
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The earth is an object of special interest to all of us. We are, indeed, attracted to it much more strongly than to any other of the heavenly bodies, of which, we must remember, it is one. For the votaries of Urania to turn from their contemplation of the heavens above to a consideration of the earth beneath is in no sense to depart from their allegiance to the Muse of Astronomy. We need not seek to justify the propriety of presenting an address on seismology before an audience of the Royal Astronomical Society of Canada.

A variety of circumstances make this place peculiarly appropriate for such a subject. We are met under the auspices of a society which has published more articles on seismology than any other in this country. We enjoy the hospitality of a university whose former president—Dr. J. W. (later Sir William) Dawson—made the first statistical studies of Canadian earthquakes.[2] The lecture room is one of those assigned to the department of physics, one of whose early professors—Doctor Smallwood—operated, as long ago as 1870, what was presumably the first seismograph to be set up on this continent.[3]

We are gathered on the flank of an extinct volcano, but on a rock foundation so solid that we should be comparatively safe in any sort of earthquake we may reasonably expect to experience in Canada. Yet within a mile of this place we can find conditions of unstable soil, coupled with old or shoddy workmanship which would certainly be dangerous were we to experience now an earthquake as

[1] Presented before the Royal Astronomical Society of Canada, Montreal Center, on Thursday, Oct. 31, 1929. Reprinted by permission from the Journal of the Royal Astronomical Society of Canada, February, 1930.

[2] Four papers by Dr. J. W. Dawson, which appeared in the Canadian Nat. and Geol., as follows:

(i) Old ser., No. 1, pp. 189–196, May 1, 1856.
(ii) Old ser., No. 5, pp. 363–372, Oct. 17, 1860.
(iii) New ser., No. 1, pp. 156–159, Apr. 20, 1864.
(iv) New ser., No. 7, pp. 282–289, Oct. 20, 1870.

[3] Last three lines of the paper by Doctor Dawson, last mentioned in footnote 2, above.

severe, say, as that which on September 5, 1732, damaged some 300 houses in Montreal alone, resulted in the death of at least one, and the injury of many under circumstances overwhelmingly less likely to prove serious than those which obtain in the same locality to-day. Those engaged in construction work in this country will some day more generally consider the known precautions with regard to earthquake tremors which should be observed in varying degree depending on the nature of the ground concerned.

Our subject is not earthquakes, however, but the earth. Astronomy first taught us something of our earth as a whole. That science was partly responsible for and greatly assisted the voyage of Columbus, which demonstrated that one could cross the Atlantic without at least falling off. The idea that the earth is spherical is now general except in Zion City, Ill. Astronomy measures for us the radius of our planet, finding it to be about 4,000 miles, the circumference being nearly 25,000 miles. Astronomy mothered geodesy, which has demonstrated that the earth is a spheroid of the oblate order. The remark about the orange which invariably follows in the schoolbooks leaves one with an uneasy sense of a religious controversy in this connection.

The shape and size of the earth being known, mathematical physics, also an offspring of astronomy, informs us that the average density of the earth is 5.6 (in c. g. s. units). It weighs, therefore, volume for volume, $5\frac{6}{10}$ times as much as water. This statement may be taken as a convenient crossover to geology. Physics and allied sciences are able to tell us only average values for conditions within the earth—the average density, the elasticity as a whole, the mean value of gravity; the details are notably lacking. The geologist is concerned with surficial details. Informed that the earth, as a whole, weighs a little more than $5\frac{1}{2}$ times as much as an equal volume of water, he states that the granite, marble, limestone, dolomite, etc., which form the bulk of our surface rocks weigh only about half as much, volume for volume, as the earth as a whole and that, therefore, there must be much denser material below. The questions throng: How far down do the surface rocks extend? What distribution of densities exists within the earth? In what physical state do the materials exist, solid, liquid, or gas? We are curious to investigate what lies within the earth beneath.

The miner has the terse expression, "Beyond the pick it is dark." [4] If this be so, how far may we penetrate below the surface. The deepest mine in the world [5] is the St. John del Rey, in Brazil. This

[4] Ambronn, Richard, Elements of geophysics (translation by Margaret C. Cobb), 372 pp. (see p. 1), McGraw Hill, New York, 1928.

[5] Science News, The age and depth of mines, Science, No. 1541, vol. 60, p. viii, July 11, 1924. A short article prepared by the U. S. Department of the Interior.

gold mine was begun in 1834. In 1924 it had reached a depth of 6,726 feet. The bottom of this mine is not, however, the point nearest the center of the earth to which man has penetrated. The Calumet and Hecla mines in Michigan, though only about 6,000 feet deep, reach a horizon 4,600 feet below sea level, said to be the point nearest the center of the earth on which man has been able to tread. The South American mines being in the mountains, their greater depth of shaft does not penetrate so far below sea level. Representing the radius of the earth by a line 120 miles in length—the distance from Montreal to Ottawa—the bottom of the Michigan mines lies at a point only 138 feet away. The number of deep mines or deep bores is small; their cost is enormous. To what depth have you personally inspected the interior of the earth?

If physics deals with generalities, geology studies details, but practically only surface details, as we have said. True, time has broken and uptilted parts of the earth's crust, exposing at the surface that which must once have lain at considerable depth. True, also, volcanoes bring up materials from below, though from what depths these materials come is not so well defined as we could wish. The geologist, having studied the earth's surface features, admits that, so far as he can learn, the average density of the surface crust is only about half as great as that of the earth as a whole. We leave him as he argues from the known to the unknown, from the observed to the conjectured, from the fact that near the surface the temperature increases about 1° F. for each 90 feet in depth to the possibility that at a depth of 40 miles the temperature may be about 2,300° F. or the "white heat of the blacksmith's forge," [6] from measures of the elasticity and compressibility of rocks under high pressures in the laboratory to conjectures as to their properties at great depths within the earth.[7] We turn to seismology for the decisive tests of any theory as to the structure of the earth on which we live and move and have our being, from which we get our means of livelihood, within which we find our final resting place; the fortress of mystery which man has, at last, completely surrounded, but which he has never penetrated, nor ever shall.

For some, an earthquake is a rare phenomenon of passing, if for the moment absorbing, interest; for others it is a dreaded nightmare of horror. To the engineer, it is a factor in his problems of design; to the insurance agent and the financier alike, it is a risk; to the newspaper man, it means business; to the geologist, it is a tectonic agent; to the seismologist, it is all of these and more.

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[6] Daly, R. A., Our mobile earth, 342 pp., Charles Scribner's Sons, New York, 1926.

[7] Daly, R. A., The outer shells of the earth, Amer. Journ. Sci., vol. 15, pp. 108–135, February, New Haven, 1928.

Our subject requires us to consider the earthquake as a release of energy—the agent which despatches a signal to be registered on the seismograph set up at each of a network of stations distributed over the globe. The signals are there recorded after having traversed the earth for various distances and along various paths, after having penetrated to various depths. The nature of the records indicates the paths by which the signals reached the instrument, the properties of the materials through which they passed. They are thus worthy of the greatest care in our choice of the network of stations, our design of instruments and vaults, our maintenance of continuous recording and accurate timing, our thoughtful study. These constitute the modern seismology, in the light of which we are to view the earth beneath.

Our first problem may be stated thus: At what depth do earthquakes release their signals? Some undoubtedly occur on the surface, though, presumably, the causal movements extend deep into the earth. Others leave no traces of permanent shift at the surface. The added fact that they are sensibly felt over wide areas indicates that they originate far below. We can arrive at a conclusion with regard to depth of focus, as it called, along different lines of reasoning. Dutton [8] used as a means of determining depth a consideration of the rate at which the intensity falls off as the disturbance spreads out in all directions from the focus and makes its effects apparent at the surface. He concludes that the maximum depth of focus is of the order of 20 miles. Walker,[9] working with Galitzin's measures of the angle at which the seismic rays emerge from the earth at the different stations in the vicinity of the focus, deduces that the depth of focus is of the order of one-fifth the earth's radius—800 miles! Omori,[10] making use of the duration of the preliminary tremors of earthquake records deduces that the mean depth of earthquakes in the Kwanto province of Japan is of the order of 21 miles. Gutenberg [11] studied the curve showing the time of arrival of the first tremors and determined for an earthquake in the Schwabian Alps a depth of 34 miles. A recent paper by Wadati [12] deals very thoroughly with the various methods. He finds that the Japanese earthquakes fall into two groups, which he terms respectively shallow and deep. "The deep earthquakes take place

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[8] Dutton, Clarence Edward, Earthquakes, 314 pp. (see pp. 185–193), Putnam's Sons, New York, 1904.

[9] Walker, George W., The problem of finite focal depth revealed by seismometers, Philos. Trans. Roy. Soc. London, ser. A, vol. 222, pp. 45–56, August 5, 1921.

[10] Omori, Fusakichi, On the focal depth of the earthquakes originating in the Kwanto Province, Journ. Geogr., vol. 34, pp. 237–241, Tokyo, 1922.

[11] Gutenberg, B., Neue Methoden zur Bestimmung der Herdtiefe von Erdbeben aus Aufzeichnungen an Herdnähegelegenen Stationen, Zeitschr. Geophys., vol. 1, Heft 3, pp. 65–75, Göttingen, 1923.

[12] Wadati, K., Shallow and deep earthquakes, Geophys. Mag., vol. 1, No. 4, pp. 162–202, Tokyo, 1928.

at the depth of more than 300 km (186 miles), while the shallow ones at about 40 km (25 miles)." Gutenberg, in a publication which has just issued from the press,[13] tabulates the values of depth of focus as determined by nine different seismologists for 16 different earthquakes. With the single exception of Wadati's deep earthquakes, the determinations all lie at depths of 28 miles or less. Seismologists generally agree that the data for determining the depth of focus are not as precise as could be desired, but that earthquakes probably originate, in general, at depths of 25 miles or less.

The uncertainty with regard to the depth of focus is due largely to our uncertainty as to the velocity of propagation of the seismic waves in the uppermost layer of the earth's crust. To determine this velocity we must have an earthquake of which we know, accurately, the time of occurrence and the depth of focus. We can be sure of this last requirement only where the depth is zero, *i. e.*, where the focus is at the surface. On February 18, 1911, a disturbance was registered which was traced to the Pamirs, in central Turkestan. Investigation showed that a great slide had occurred in which from 7 to 10 billion metric tons of rock had fallen a distance of from 400 to 800 yards. The tremors, registered on the seismographs at Ottawa and generally throughout the world, were believed to have been the result of the rock fall.[14] The exact time of the fall could not be determined. Moreover it is now questioned whether the fall was the cause or the result of the earthquake.[15] Such a question could be raised in the case of practically any such earthquake. We fall back upon the velocity of earth tremors generated by an explosion.

The velocity of seismic waves has been studied in the case of a great explosion at Oppau, in the works of the Badische Analin und Sodafabrik in the Bavarian Palatinate, on September 21, 1921.[16] The tremors were registered at five seismograph stations ranging in distance from 68 miles to 227 miles. The chord from Oppau to De Bilt—the farthest station—dips only about 2 miles below the surface at the middle of the arc. We may thus consider the waves as being well within the upper layer of the earth. The exact time of the explosion is known within one second. The records give the velocity of propagation of the most rapid tremors as 5.4 km (3.35 miles) per second.

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[13] Gutenberg, B., Theorie der Erdbebenwellen, Gebrüder Borntraeger, Handbuch der Geophysik, vol. 4, Lief. 1, 298 pp. (see p. 234), Berlin, 1929.

[14] Klotz, Otto, The earthquake of Feb. 18, 1911—A discussion of this earthquake by Prince Galitzin with comments thereon—Journ. Roy. Astron. Soc. Canada, vol. 9, pp. 428–437, November, 1915. (See also footnote 16.)

[15] Macelwane, James B., S. J., Are important earthquakes ever caused by impact? Bull. Seism. Soc. America, vol. 16, No. 1, pp. 15–18, March, 1926.

[16] Jeffreys, Harold, The earth, 278 pp. (see pp. 169–170), Cambridge University Press, 1924.

But one swallow does not make a summer. It was desirable to check the value of the velocity by means of other explosion records, especially as the velocity as determined for waves generated by earthquakes of presumably shallow focus was found to be 7.1 km (4.4 miles) per second. Accordingly, in May, 1924,[17] four explosions, the first two of 10 metric tons each, of melinite, the second two of 5 metric tons each, were exploded at La Courtine, in central France. The explosions being predetermined, arrangements were made to have precise timing and fast-speed chronographs, so that the records obtained were spread out sufficiently to be readily legible. The tremors were registered at three stations ranging in distance from 3½ to 15½ miles. The mean value of the determined velocity for the most rapid tremors was found to be 5.5 km (3.4 miles) per second, confirming substantially the results obtained from the records of the Oppau explosion.

This raises a further point. We have referred only to the velocities of the first movement as registered on the seismograph. The fact that high-speed chronographs were used at La Courtine to spread out the record implies that there were other onsets of value. There were.

Waves propagated in an elastic body (that is to say, a substance which has the power of recovering its shape if it is not strained beyond certain limits—and the earth is such a body) are of two kinds. The first is known as a longitudinal or dilatational type and the waves so propagated are called P waves, since they are the primary or first registered. The other type is called transverse or distortional, the waves being termed S waves because they are the secondary registration in point of time. The P wave and the S wave each travel through the earth from the focus to the station by paths which may be for the present described as being somewhat concave upward, or as sagging below the chordal line joining the focus and the station. The velocity of each depends on the elastic properties of the earth, being greater in each case if the elasticity of the material along the path increases, but slowing down for an increase in density. The S wave has the added important characteristic that it can not be propagated through a liquid.

The velocity of the first, fast tremor, found to be 5.4 km (3.35 miles) per second in the case of the Oppau explosion, and 5.5 km (3.4 miles) per second, on the average, at La Courtine, was that of the longitudinal vibrations—the so-called P wave. The velocity of the S wave was found to be 3.1 km (1.9 miles) per second at Oppau and 2.8 km (1.7 miles) per second in the mean at La Courtine—

[17] Maurain, Charles, Eble, L., and Labrouste, H., Sur les ondes sismiques des explosions de la Courtine, Journ. Phys. et le Rad., vol. 6, No. 3, pp. 65–78, March, 1925.

again a fair agreement. We thus have a measure of the velocity of propagation of the two types of waves in the uppermost layers of the earth's crust, based on observations of five separate explosions, registered at three or more stations in each case. Obviously we wish to add to our observational data of this nature.

To quote from our legal friends, "time is to be the essence" of our experiments. The nearest of the La Courtine stations was 3½ miles from the blast. The first tremor, marking the time of arrival of the P wave, registered about one second after the explosion. The S wave required about two seconds to travel the same distance. The difference in time of arrival was thus about one second in the case

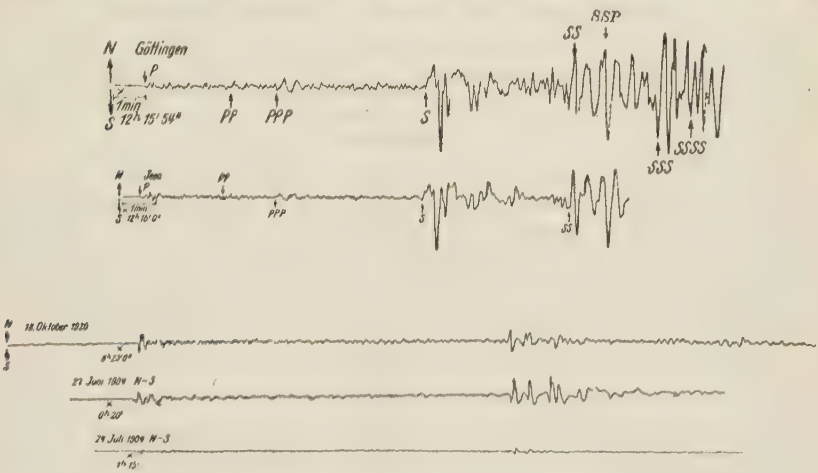

FIGURE 1.—Upper group: Seismograms registered at Göttingen and Jena, respectively, of an earthquake in Kansu, China, 1920, December 16. Lower group: Seismograms registered at Jena, of earthquakes in Kamchatka, on the dates indicated. (This illustration has been copied from Gutenberg's discussion of "Fernbeben," in Borntraeger's "Handbuch der Geophysik." See footnote 13)

of the nearest station and about four seconds in the case of the farthest. To render the onset of the S wave legible it was necessary to record the tremors at a higher speed than that generally used for earthquakes. Obviously, if the distance is increased to several hundreds or thousands of miles, the difference in time of arrival will be increased and, moreover, slight inaccuracies in the determination of the exact instant of arrival of either phase will not greatly affect the velocity determination.

In order to convey some idea of the manner in which the two types of waves make their appearance on a seismogram, the two groups of records of Figure 1 are shown. The arrival of P and S is indicated for the two seismograms of the first group. These are

records registered at Jena and Göttingen, respectively—two German stations about 80 miles apart—of an earthquake which occurred at Kansu, China, about 4,600 miles from the recording stations. One minute of record line is indicated at the beginning of the record and successive minutes can be seen on the original records as breaks in the line, a few of which are preserved even in the reproduction. The difference in time of arrival of S and P is here about 8 minutes and 50 seconds. To obtain a record such as this a line recording speed of from half an inch to an inch and a half per minute would ordinarily be employed, depending on the seismograph used and the purpose of the registration. Where S and P arrive within a second or so of each other, as in the case of a blast or explosion, it is customary to have a line recording speed of 6 or 7 inches per second. Such a short-distance but spread out record would resemble those registered at Göttingen and Jena for the Kansu quake except that the serrations would be more numerous.

The second group of records is also interesting. It shows the seismograms registered at Jena for three earthquakes, each of which originated in Kamchatka—about 5,300 miles distant—in October, 1920, June, 1924, and July, 1924, respectively. This shows how strikingly alike are the records of the same instrument for earthquakes originating at the same epicenter.

A friend of mine, a devotee of bridge, sometimes mutters a brief prayer in the words, "through strength and up to weakness." Let us repeat this solemn incantation now in order that you may be properly impressed with the strength of that part of seismology which has become so well established that it now forms the strong supporting column of the seismological attack on the problem of the internal structure of the earth. If, at the close of this address, you feel that the van of that attack is occupying ground which it may not be able to hold indefinitely, do not forget that all will not be lost in any event. We are sure of some things—and rather interesting and somewhat surprising things they are, too.

We know, from long experience, that if an earthquake takes place as a sharp, well-defined, single shock, it will be registered at stations which are more than 700 miles and less than 7,000 miles distant in such a manner that the arrival times of P and S can be definitely determined, the difference computed, and the distance from station to epicenter (that point on the surface vertically above the focus) read off from an empirical table or its graph to within 25 or 50 miles. Furthermore, we can, if the stations are equipped with proper apparatus for recording absolute time, determine the time at the epicenter so accurately that the values derived from the records of stations at distances within the above limits will agree within a few

seconds. Moreover, the distances from each of three or more stations being known, for any given earthquake, the position of the epicenter can be determined with a surprising degree of accuracy. And, finally, this work has been done, with ever-increasing accuracy, by various agencies since 1899, supplementing previous catalogues of felt earthquakes and giving us an analysis of the relative seismicity of the different parts of the earth's surface, which is very good, indeed. This analysis is being continuously strengthened to-day by the efforts of over 200 stations, regularly operating seismographs and publishing data. Our time distance curves are subject to but minor corrections for distances between 700 miles and 7,000 miles. We know our seismic areas. The seismic history of many of these areas is already long continued enough to be of value in various lines of investigation. From this hard-won but firmly consolidated position we step forward into the front-line trenches, the active sector of seismological research.

To detail the various investigations which combine to give us our present tentative conception of the internal structure of the earth is beyond the limits of this address. It must suffice that, after outlining that conception, the seismological evidence supporting it be briefly inspected. The methods adopted for checking the details of the proposed earth structure will serve to give us some idea of the procedure by which that structure has been inferred.

All seismologists agree that the earth has a spherically layered structure, consisting of a central core surrounded by a series of shells of different thickness, each with its own distinct properties. The spherical surfaces separating the various shells are probably fairly well defined; that is to say, the transition is relatively sudden. They are referred to as surfaces of discontinuity, or simply as discontinuities.

Let us consider first the central core. The surface of discontinuity surrounding it is believed to lie about 2,900 km (1,800 miles) beneath our feet, or a little less than half the distance to the center of the earth. The material of the core is believed to be iron, with probably some nickel as well. If our earth is made of the stuff of which other worlds are made (and that seems a reasonable assumption) and if the meteors which occasionally fall to the earth are to be regarded as samples of that material then we may infer a mixture of iron and nickel for the central core. Here we have a large part of the extra density demanded by the physicist to make up for the light surface rocks and average up the density of the earth to the 5.6 which he demands. The existence of the core is rather well established. The P waves are refracted into its surface in such a manner that they fail

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to reach stations which are between 7,000 miles and 10,000 miles of the epicenter, leaving the so-called blind zone as shown in Figure 2.

In what state is the iron of the core—solid, liquid, or gas? The question is still an open one. The fact that the S wave will not be transmitted through a liquid or a gas suggests that we apply that criterion. This is not as easy as might be supposed. Some seismologists believe the S wave has been identified after transmission through the core. Most are agreed, however, that it has not been positively identified, and some are frankly of the opinion that the central core is liquid or gas. It is supposed to be dense, under high pressure, of course, but not an elastic solid. The velocity of the P wave is high for the layer just outside the central core—about

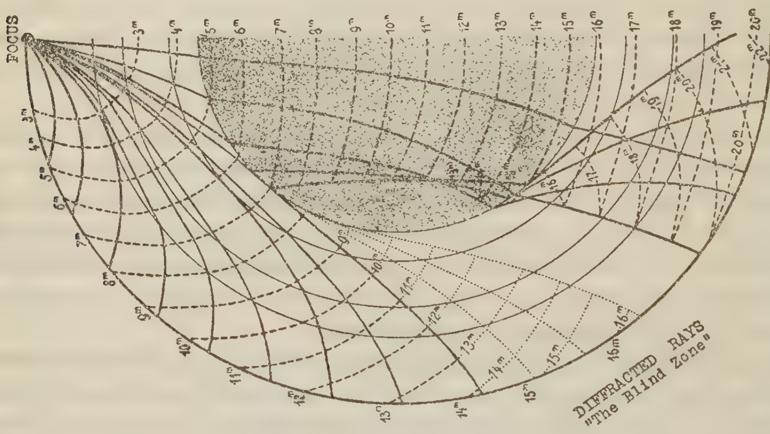

FIGURE 2.—Cross section through the earth, showing the path of propagation of characteristic longitudinal waves. (Adapted from Gutenberg's contribution to Borntraeger's Handbuch der Geophysik. See footnote 13)

13 km (8 miles) per second. Within the core it drops suddenly to 8.5 km (5.3 miles) per second. Does the density suddenly increase as you pass into the core, or does the elasticity become markedly less? Always we are left with questions, unanswered as yet but not unanswerable. Of such is the kingdom of research. Without them we should develop an orthodoxy of science which would be fatal.

The surface of discontinuity at the central core is, as has been noted, well defined. It is indicated by the "blind zone" and also by the sudden drop in velocity, which, in turn, indicates either a sudden increase in density or a rapid falling off in elasticity or a combination of these. The fact that there is a sudden drop in velocity is deduced mathematically from the observational data of earthquake records—the so-called time-distance or travel-time curves. A paper by Knott[18] presents the method by which this is done. A

[18] Knott, C. G., The propagation of earthquake waves through the earth and connected problems, Proc. Roy. Soc., Edinburgh, vol. 39, pt. 2, No. 14, pp. 157–208, 1918–19.

recent book by Gutenberg (pp. 32–80 of reference 13) outlines the work of recent writers on this subject. There is no other such well-marked sudden change of velocity with increase in depths as that which occurs at the entrance to the core. The other changes are less abrupt and are, in general, *increases* in velocity. The other discontinuities are thus not so well established, in fact or in position, as is that at about half way down the earth's radius.

Ascending from the 2,900 km level we traverse, in turn, three layers of slightly different properties, the two discontinuites separating them being so ill defined that we are not sure where—or even whether—they are. The discontinuity which surrounds the triple layer is at a depth of 1,200 km (750 miles). The material composing these three layers is supposed to be silicon impregnated with iron. The iron content is supposed to increase for points successively nearer the core, and to be very small at the outer boundary at the 1,200 km discontinuity. The three ill-defined layers, taken together, constitute what is known as the transition layer. The transition layer and the core, taken together, are sometimes known as the "nife" (ni=nickel: fe=ferrum=iron).

The next discontinuity is much better marked; its existence is certain; there is some uncertainty as to its position. It may chance to be different in different parts of the world. Much remains to be done in its investigation. The break is usually held to be at a depth of 60 km (37 miles). It marks the upper boundary of the shell of silica and magnesium usually designated as the "sima" (the name indicating the constituents). The increase in velocity with depth within this layer is so uniform that it is not believed to suffer any internal discontinuities. The density inevitably increases somewhat with depth due to the superimposed weight; the elasticity must thus gradually increase downward at a fairly uniform rate in the sima, and at a less regular rate in the transitional layer of the nife until finally we get the great reversal, the fall in velocity, at the central core. Let us come back toward the surface and nearer home. What is the constitution of the upper 60 km (37 miles) of the earth's crust?

Jeffreys [19] believes that there are three layers, separated by discontinuities at depths of 12 km (7.5 miles) and 37 km (23 miles). These he terms, in order descending, the granitic layer, the basaltic layer, and the ultrabasic layer, thus indicating the probable nature of their constituent rocks. The three taken together are known as the "sial" (si=silicon; al=aluminum).

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[19] Jeffreys, Harold, On near earthquakes, Monthly Not. Roy. Astron. Soc., Geophys. Suppl., vol. 1, No. 8, pp. 385–402, December, 1926.

To sum up, then, beginning at the surface and continuing downward, we have, in order, a layer of granitic rock 12 km (7.5 miles) in thickness; 25 km (15.5 miles) thickness of basalt; a 23-km (14 miles) layer of ultrabasic rocks; 1,140 km (700 miles) of silicon-magnesium—the sima; a transition layer of silicon impregnated with iron, of a total thickness of 1,700 km (1,060 miles); and, finally, a great nickel-iron core of radius 3,470 km (2,150 miles). The best marked discontinuities are those at 60 km and at 2,900 km.

Figure 3 shows in schematic form the various layers.

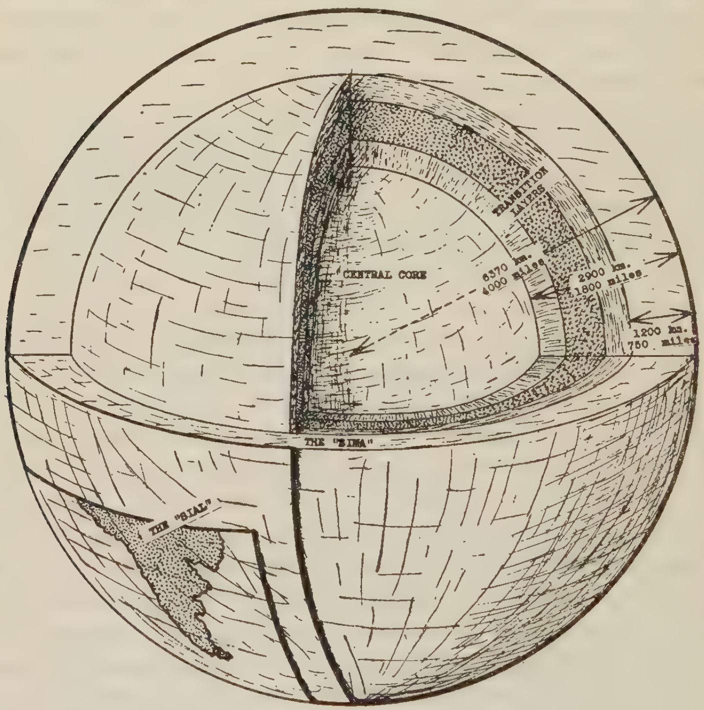

FIGURE 3.—The structure of the earth

The discontinuities about which we should most like to know more are those at 12 km, 37 km, and 60 km. We shall learn more about them only through a study of earthquake waves and waves generated by explosions. If you look over the edge and into a cup, diagonally so as to just miss seeing a coin placed in the bottom of the cup at the side nearest, and then pour water into the cup, the coin becomes visible, due to the bending of the light ray as it passes from the water into the air—a phenomenon of refraction. The echo is a familiar example, in sound, of the phenomenon of reflection. Earthquake waves are refracted in passing from material of given density and elasticity into a second with different properties, i. e.,

in crossing a discontinuity. They are reflected on reaching the surface or at the inner side of the great discontinuity at 2,900 km depth. Seismologists name the various phases appearing on their records according to the paths they have probably taken. For example $\overline{S_cP_c}\ \overline{P_cS}$ represents a wave which began as a transverse vibration, traversed the discontinuity at the core ($_c$); went on as a P wave but was totally reflected at the inner face of the 2,900 km discontinuity; proceeded as P; again traversed the core and completed its journey to the seismograph as a transverse wave. Figure 2 shows some of the waves going directly through the core, refracted but not reflected. These are designated the P′ waves.

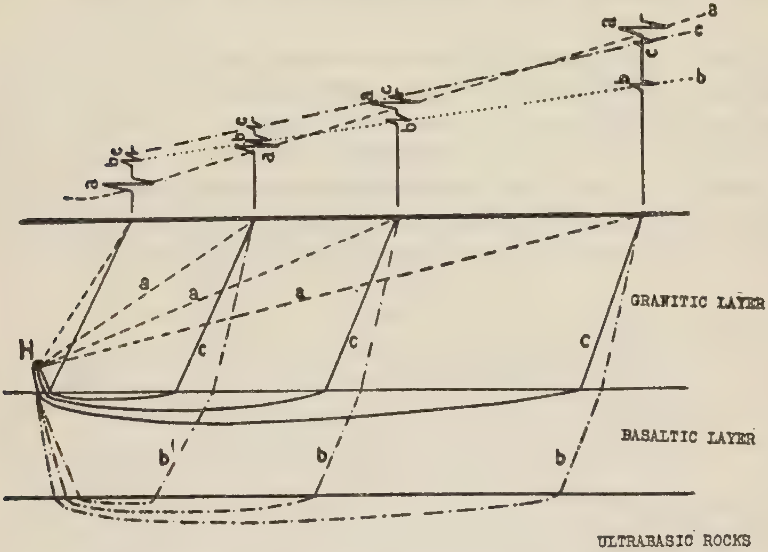

FIGURE 4.—Diagram of the paths of propagation of the longitudinal waves through the upper layers of the earth (after Gutenberg, see footnote 13)

Where reflection takes place, bars above the letters bracket each leg of the path, as indicated in the extended symbol above.

Near the surface we have a multiplicity of refractions. Figure 4 shows some of the paths which have been suggested as possible.

It will be seen that we have a very large number of wave arrivals on our seismogram; at least that we may expect many. As a matter of fact, some arrive with such small energy content that they register but faintly. This, nevertheless, affords a further check on the theory, as that theory attempts to predict which waves should register thus. The proposed structure may thus be checked in many ways by means of longitudinal and transverse internal or body waves of earthquakes. We have not mentioned that there are also two types, at least, of surface waves. These also serve to throw light on the study of the

outer earth shells. Time fails for us to enter on a discussion of what is known as seismic prospecting, by means of which commercial interests probe the upper 4,000 feet or so of the earth's crust in the search for oils and minerals. They delineate many of the details of the upper layers, but, from a purely scientific standpoint, the most interesting result is the large mass of data showing the relation of the wave velocity and the type of material traversed.

We have outlined, then, the present theory of the structure of the interior of the earth and indicated the means by which it is to be checked and improved through a study of seismic waves. If a later modification of the theory should give traveltime curves more nearly in accord with later and more accurate data, the modification will be adopted. The present theory is (in the language of the automobile prospectus) the latest model, which we take pleasure in exhibiting at this time. We hope it will find its way into the hands of many and that they may enjoy the fullest service in its use. It may be traded in as soon as suggested improvements have been found worthy of adoption. All may rest assured that when better theories of the internal structure of the earth are built, seismology will build them.

COMING TO GRIPS WITH THE EARTHQUAKE PROBLEM [1]

By N. H. Heck

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[With 8 plates]

On February 2, 1931, we had another reminder that the problem of safeguarding cities against damage from severe earthquakes is as yet unsolved when the beautiful coast resort city of Napier, North Island, New Zealand, was nearly destroyed by a great earthquake. This earthquake also demonstrated that in designing structures to resist earthquakes the possible cumulative effects of a number of severe shocks must not be overlooked, since there were at least three aftershocks comparable with the main shock.

The earthquake is always of absorbing interest to the seismologist, but we are rapidly approaching a condition in which the heretofore sporadic interest of the average citizen is being converted into continuous interest in many parts of the earth, and accordingly the engineer and architect in the regions concerned are beginning to be quite as much interested as the seismologist.

The two fields of activity with regard to earthquakes—geophysics and engineering—although having different purposes, are not independent, and results in either field may throw light on the problems of the other. Prominent engineers have begun to criticize the seismologist for not giving them the information that they need, and the time now seems ripe for closer coordination of activity.

From the viewpoint of the geophysicist, earthquake investigation is for the purpose of learning all that there is to know about the nature of the earthquake itself as a physical phenomenon and the transmission of waves, and, incidentally, the nature of the transmitting medium, with consequent information about the interior of the earth, which is obtainable in no other way. From the viewpoint of the engineer, the important factors are the probable occurrence of a severe earthquake in a given locality, the effect of earth-

[1] Lecture presented at a meeting of the Franklin Institute held on April 2, 1931. Reprinted by permission, with considerable alterations, from the Journal of the Franklin Institute, vol. 212, No. 3, September, 1931.

quakes on structures, and the design of structures to resist or reduce destruction by earthquakes. There is particular interest in regard to the large structures which modern civilization makes necessary, such as office buildings, factories, bridges, high dams, and other structures.

For a number of years engineers have been gathering information regarding earthquake effects on structures and to some extent are basing design of structures on the observed facts. At Stanford University they are operating a large shaking table on which types of structure and models of buildings are tested under conditions simulating earthquakes. With all this, they feel the need of more exact knowledge in regard to motions of strong earthquakes, a demand which the seismologists have not yet met.

The reason for this is a practical one. Seismologists, like engineers, have to be practical. Severe earthquakes are of relatively infrequent occurrence at any given place, even where great damage has occurred in the past. Instruments suited to record strong motions will not record weak ones. Accordingly, in order that we may have material with which to work, the instruments must be able to record earthquake waves coming from a considerable distance, but instruments able to do this will not record strong motion. The valuable information which the seismologist has been able to obtain about the interior of the earth has been accompanied by the introduction of many perplexing problems. It is, therefore, not surprising that much energy has gone into perfecting instruments and methods for recording distant earthquakes. In fact, the principal problems in this field are well on the way to solution, though we may continue to expect new instruments and methods from time to time.

The seismologist in developing these instruments has acquired much information which is useful for the design of the more rugged and relatively insensitive instruments which must be used to record strong motion. His knowledge of wave transmission will also be essential to the correlation of the information regarding strong motions when available. It is for the engineer to state exactly what information he needs and to make use of it after it has been obtained. The seismologist by his previous accomplishment has justified the confidence of the engineer in his ability to solve the problems.

This accomplishment has included both instrumental development and the development of theories to explain the complexities of the records in terms of transmission through the earth and, consequently, reasonable deductions about the physical conditions of the other-

wise unexplored medium through which the waves pass—the interior of the earth.

The working tool of the seismologist is the seismograph. The present seismographs, several types of which will be described, have as their purpose as accurate recording as possible of the earth motions during an earthquake. They have been developed from the simple pendulum and many of them employ the principle of the horizontal pendulum. In this the weight or mass which corresponds to the pendulum bob is held at a distance from a vertical support by means of a boom which rests against a point near the bottom of the support through a pivot to reduce friction. A diagonal wire from the weight to a point near the top of the support carries the weight. The system is then a triangle free to swing with one side as a nearly vertical axis (pl. 1, fig. 2). In an actual earthquake the earth and the vertical support move and through inertia the mass remains momentarily at rest. It is known as a steady mass. If the earthquake continues the mass will take up motion and provision must be made for this. In any case the record or seismogram is a result of the different motions of the earth and of the steady mass. The developments of the past 50 years have been directed toward securing the best solution of the problem and toward refinements which give the desired accuracy for recording distant earthquakes.

Earthquakes occur in a 3-dimensional medium and waves approach the seismometer from different directions according to relation of position of earthquake to that of instrument. In the case of the horizontal pendulum the record will be quite different if the axis of the boom is directed toward or away from the earthquake or at right angles to this line. Obviously the instrument must have a permanent position, so the plan has been adopted of having two instruments at right angles to each other and also, where possible, a third instrument to respond to vertical waves. Formerly the horizontal instruments were placed in north-south and east-west directions. The practice is now being developed of having the axis of one boom point in the direction from which the greatest number of earthquakes may be expected and the other is set at right angles to this. For convenience we speak of the three components of a seismograph, though each is a complete instrument in itself. Even though the practice of directing the axis of one component as stated helps to simplify the record, the results are not entirely satisfactory and it is a very difficult problem to analyze completely the records of an earthquake arriving from some other direction than those of the two axes.

Horizontal component instrument.—In most of these the principle of the horizontal pendulum is used. For stability combined with high sensitivity the line joining the upper and lower points of support must be slightly out of the vertical. Adjustments are provided to make this possible.

Damping.—In order to prevent the seismograph from oscillating in its own natural period and producing a very complicated record, the pendulum is damped, which means that a suitable vane attached to it moves in an oil well, an air pocket, or in a magnetic field, any of which will serve as a brake. If the period of the earthquake and that of an undamped pendulum are equal or nearly equal, resonance is set up and the pendulum movement as recorded has no relation to the earth movement. Damping can not be perfectly effective, but the aim of the seismologist is to make the damping arrangement as effective as possible.

Magnification.—In the case of distant earthquakes the actual ground movement, if it were directly recorded, would be invisible for all but the very strongest earthquakes. For near earthquakes of considerable strength, the magnification must be small. There is in practice a wide range of requirements. Various instruments use magnifications of approximately 1,200, 700, 150, and 5 or 2. For special purposes magnification of 1,000,000 has been used. By optical or mechanical means the actual movement of the mass or, rather, of the supporting frame with respect to the mass, can be multiplied to a considerable degree, and this is known as static magnification. For a record the magnification to be used differs from this and the so-called harmonic magnification varies with periods of earth wave and instrument and with the damping, and therefore for the same instrument magnification will vary with the earth period.

Period.—The period is the interval of time between two successive passages of a pendulum through the position of rest in the same direction. For recording near-by earthquakes, short-period instruments are used, both on account of the short periods to be recorded and because of the necessary optical and mechanical requirements to obtain the desired magnification. In the case of distant earthquakes there is a wide range of periods and several might be chosen for the instrument. Periods of 12 to 15 seconds are in quite general use.

Vertical component instruments.—In these a mass is supported by a spring, and the difficulty is to secure stability along with great sensitivity, large magnification, long period, and freedom from changes due to temperature.

Time.—The accuracy of the time is of great importance. Uniform speed of rotation is one element and absolute time is another, and both must be satisfactory. Even with the best of apparatus small

departures from uniform rotation are likely and, therefore, it is desirable to have all components record on one drum or on several drums on the same shaft (pl. 2, fig. 2). The same activity will not then be recorded at different times because of variation in speed of several independent drums, and this is an advantage even if the absolute time is in error. Time marks from a good clock are placed on the record and time signals by radio are recorded directly on the seismograms, and if this can be done with sufficient frequency errors can be kept small (pl. 3, fig. 1). Rev. James B. Macelwane, S. J., in a paper before the section of seismology, International Geodetic and Geophysical Union, last summer stressed the importance of time and showed that there is grave danger of assumption at many seismological stations that the accuracy is greater than it actually is.

Galvanometric recording systems.—In such systems the boom, in addition to carrying the mass, has a coil which moves in the field of a strong magnet. The currents set up are recorded through a galvanometer. This system has the advantages that high magnification can be readily obtained, damping is not difficult, and tilting of the pier is not recorded on the record. Also, it is at times a great advantage to have the seismometer at a place specially suited to this purpose and the recorder at another place at some distance away, where conditions are better suited for recording. The distance may be considerable if conditions require it.

In the case of most horizontal component instruments with long periods, as 12–15 seconds or more, tilting of the pier may seriously confuse the record. The effect is to put successive lines on the record too far apart or, more serious, to crowd them so close that an earthquake record can not be interpreted. This tilt is usually due to local temperature effects on the building or on the pier itself. The effect of tilting is eliminated in the galvanometric recording system and in the case of short period instruments, and it is very desirable to eliminate it on other types. This has been accomplished successfully in an instrument which will be described later.

Examples of instruments which embody these principles.—The Wood-Anderson torsion seismometer, through the use of a very small cylindrical mass or a vane attached to a vertical fiber under tension is able to get a short period with high magnification and so is able to respond to and to magnify ground movements of very short period. It is probably the best instrument in existence for the study of near-by earthquakes. It was developed at Pasadena, Calif., for the special studies that are being made there. While ordinarily operated at a period of less than 1 second, it has been operated at 6 seconds, and the Coast and Geodetic Survey is operating such an instrument at Tucson, Ariz. It not only gives good records of dis-

tant earthquakes, but gives useful records of earthquakes at moderate distances, as in the Imperial Valley and elsewhere in southern California and adjacent Mexico, so that the records are useful in connection with the special investigations being made in southern California (pl. 3, fig. 2).

Galvanometric recording is used in the Wenner seismometer, developed by Dr. Frank Wenner, of the Bureau of Standards (pl. 2, fig. 1). This instrument has been fully described in publications of the Bureau of Standards [2] available to anyone interested. It is operated at high magnification and gives exceptionally good records, except when microseisms interfere with interpretation of the records. Microseisms are small oscillations set up at times in the earth's crust, and, according to various investigators, are to be attributed to effect of breakers on the coasts, and, more probably, to passing areas of considerable range in barometric pressure. They may last for several days and in the case of instruments of high sensitivity may make it impossible to interpret a superimposed earthquake record. These instruments are installed at San Juan, P. R., at the observatory of the Coast and Geodetic Survey, at the Cathedral of Learning at Pittsburgh, Pa., and will soon be installed at the station of the Massachusetts Institute of Technology near Machias, Me., and at the observatory of the Coast and Geodetic Survey at Sitka, Alaska, and also in the new Franklin Institute Museum in Philadelphia.

The McComb-Romberg tilt compensation seismometer has tilt compensation in effective form (pl. 1, fig. 2). The instrument has been developed by H. E. McComb, of the Coast and Geodetic Survey, using a principle developed by Arnold Romberg, now of the University of Texas, but at the University of Hawaii when he did the work (pl. 4). The instrument has photographic recording with relatively simple and compact optical system, oil damping, and magnification of about 150. Its distinctive feature is oil coupling between boom and recording mirror. The mirror, which is horizontal, has a vertical stem or shaft which carries a vane. The vane is free to move in a long rectangular container of castor oil, which is attached to the steady mass. The mirror is pivoted on a horizontal axis so that it tilts with every movement of the vane. All rapid movements are transmitted from liquid to vane as if the connection were rigid. If, however, owing to tilt, the boom takes a new position, the vane drifts through the liquid with the mirror remaining horizontal. Since the tilt and drift are both very slow, the record is not affected.

[2] Wenner, Frank, A new seismometer, etc., Research Paper No. 66, reprint from Bureau of Standards Journ. Research, vol. 2, May, 1929.

With the instruments that have been described or others with similar characteristics, it is possible to have seismograms to meet the needs of particular investigations.

It would appear at first thought that there would be such a complexity of waves from an earthquake that they could not be sorted out. However, through absorption of energy and the results of reflections and refractions within the earth or at its surface only certain waves have sufficient energy to arrive. The definite arrivals of these

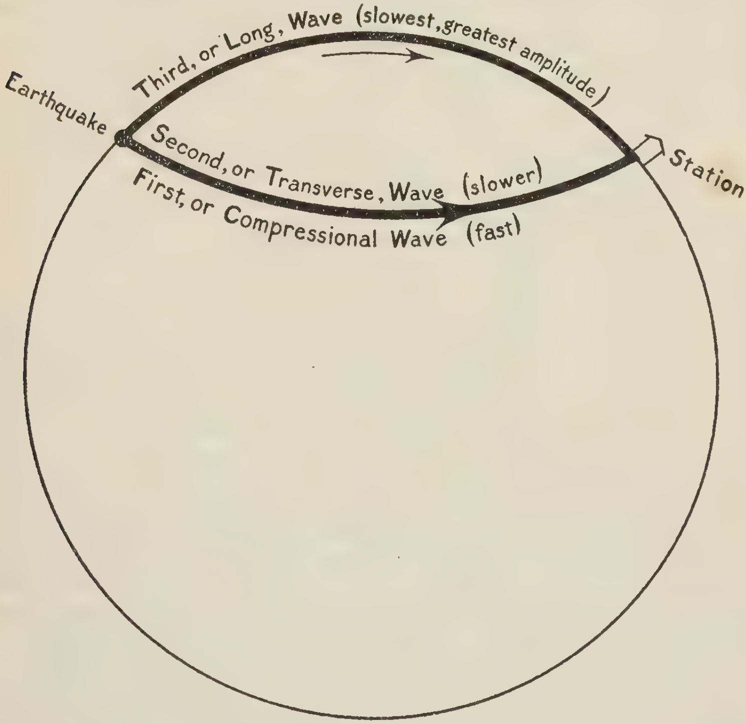

FIGURE 1.—The difference in times of arrival of the longitudinal or high-speed wave and the transverse or slower-speed wave is a measure of the distance from the earthquake to the seismological station

so-called phases are indicated by sudden or gradual increases of amplitude or by sudden change of period, or both, and these form an orderly succession, some of which can be distinguished in all intelligible records. Since many of those present have probably not gone far into the subject, I will recapitulate the principal facts.

We have the preliminary tremors, designated P for primus, which are longitudinal; that is, with vibration in the direction of progress. These follow a direct path from earthquake to recording station, but a curved one, dipping somewhat below the straight line connecting these two points. Their velocity near the surface is 7 to 8 kilometers

per second and their ordinary period 5 to 7 seconds. The second preliminary, designated S for secundus, is a transverse wave with vibrations at right angles to direction of progress. The velocity near the surface is about 4.5 kilometers per second and the period is 11 to 13 seconds. The path is approximately that of the P wave.

Reflections of these waves may occur at the earth's surface at the halfway point or even at two points, respectively, one-third and two-thirds of the way with sufficient energy to be recorded. The first case is designated as PR_1, SR_1, and the latter PR_2 and SR_2.

The longitudinal waves which pass along the surface are more complex. Their speed is 3 to 4 kilometers per second, according to

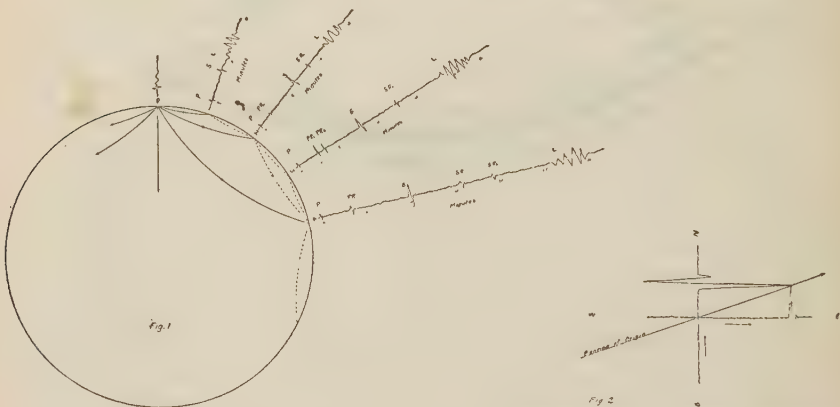

FIGURE 2.—Paths of earthquake waves and types of seismogram at different distances from an epicenter

There may be one or more reflections of the different waves at the surface and these reflected waves reach the seismograph station later than the unreflected waves. Such phases may be recognized on some seismograms, their prominence depending upon the distance to the epicenter, path over which the waves travel, component, etc. Insert: In some cases the phases on different components of the seismograph are so well defined that the direction of the epicenter may be estimated from the ratio of the amplitudes recorded by two instruments operating at right angles to each other.

conditions. The velocity for a path entirely beneath the Pacific Ocean is about 20 per cent greater than under the continents. The directions of vibrations are more varied than for the preliminary waves. The periods vary greatly and may be very large, as 40 seconds or even a minute.

While much more might be said, these statements give the essential facts. It is not, however, the whole story. When the distance exceeds 10,000 kilometers, the waves pass through the central metallic core of the earth, and this modifies the paths so that the system of phases that has been described is replaced by another. However, since my purpose is to discuss the central and surrounding region of an earthquake, I will not go into this.

The actual use of the complex phases is made possible through diagrams with distances plotted as ordinates and intervals in seconds from time of origin of the earthquake as abscissas. Tables are also used in which time intervals from time of the earthquake to arrival of the given phase, or intervals between successive phases, are given for each distance. Perhaps the most convenient tables that have been developed are those of Rev. James B. Macelwane, S. J., of St. Louis University. However, not all tables are in full agreement, and seismologists are still working on the best values to adopt in some cases.

An important use of these diagrams and tables is to obtain distance of station from earthquake in order that the earthquake epicenter may be known. The epicenter is the point on the surface directly beneath which the earthquake occurred. This can be located in several ways but the graphical method of plotting on a large globe need alone be mentioned. The positions of seismological stations are marked on the globe and, by means of compasses, arcs are swung from each for the given distance of the earthquake. The intersection of the arcs gives the position of the earthquake (pl. 5). Some years ago little use was made except of records giving clear P and S phases. Now earthquakes can be located when these phases are lacking on all available records. Such a location was made of an earthquake in China, which later was found to agree with the determination made from all available data, including those of near stations. An adopted epicenter must meet the requirement of reasonably good intersection of the arcs, and the times of origin of the earthquake as computed from the several records must be in good agreement.

The tables and curves have been derived from study of records and from theory. Certain assumptions are made, and if these agree with a large mass of observational results they are held to be valid.

In this way a solution can be found for the distribution of density within the earth. Knowing the surface density and the mean density as given by astronomy, a distribution can be worked out which fits the velocity of seismic waves at all distances.

If the observations fit adopted curves through a wide range and then the agreement suddenly disappears, an explanation must be found; in this way the existence of certain layers of discontinuity has been postulated. We do not know exactly what the significance of a layer of discontinuity is, that is, whether there is a change in physical conditions or in chemical composition, though there is evidence in favor of both. We know from seismic evidence that such layers exist because the characteristics of recorded earthquake waves can not otherwise be explained. The best known and most definite of these is

the one at 2,900 kilometers that bounds the central core of the earth which geologists believe to be of iron and nickel. The ability of this core to change path and energy of the earthquake waves is beyond argument. It has also been held that the interior, though at very high pressure and temperature, behaves like a liquid in its inability to transmit any but longitudinal waves. Transverse waves are practically lacking, though Doctor Macelwane [3] has recently found evidence that they may exist.

Of more importance to our discussion are layers near the surface. These are not so definite and there is more difference of opinion. In records of near-by earthquakes there are often two P phases and sometimes three, and the same may be true of S. An explanation is called for. The first was that of Mohorovicic who postulated a layer of discontinuity 60 kilometers beneath the continents, and this seemed to give fairly good agreement with observations (fig. 2). Changes

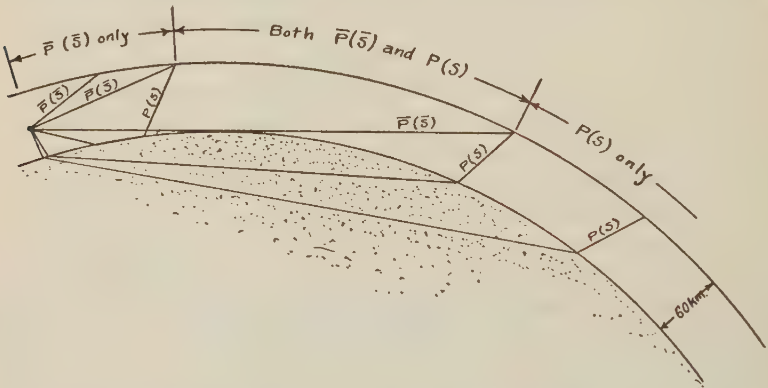

FIGURE 3.—Illustrating the refraction of earthquake waves when reaching the supposed 60-kilometer layer below the surface. Reflected waves are not shown

in velocity throughout the layer, taking place in a manner similar to that worked out for the deep interior of the earth, were necessary. Observations of submarine earthquakes gave evidence of a much thinner layer beneath the oceans and this in turn corresponds to the faster surface waves beneath the oceans which have been mentioned.

Seismologists in general had accepted this conclusion almost universally when Jeffreys suggested a different explanation. As shown in Figure 4, his theory calls for two layers of discontinuity about 10 and 30 kilometers, respectively, below the surface. Most of the energy passes along these surfaces and the velocity of the waves remains nearly constant throughout their paths. Seismic prospectors use a somewhat similar theory for layers very near the surface. Investigations in California fit Jeffreys' theory very well.

[3] Macelwane, J. B., South Pacific earthquake of June 26, 1924, Gerland's Beitr. Geophys., vol. 28, 1930.

The consideration of these layers brings us to a very important question—the depth of focus or depth beneath the surface at which the earthquake occurs. This is of importance in the case of distant earthquakes, but it is far more important for those occurring near by. Theoretically there should be important differences in the records of two earthquakes at the epicentral distances of, for example, 200 kilometers, but with one having a depth of 20 kilometers and the other 40.

Methods for determining depth of focus are not yet satisfactory, and in order that such determinations may be undertaken, there must be a large number of precise records from near-by stations and time must be accurately measured to the nearest tenth second. The latter requirement is met at very few stations and the former only in parts of Europe and in Japan, though before long the eastern and extreme

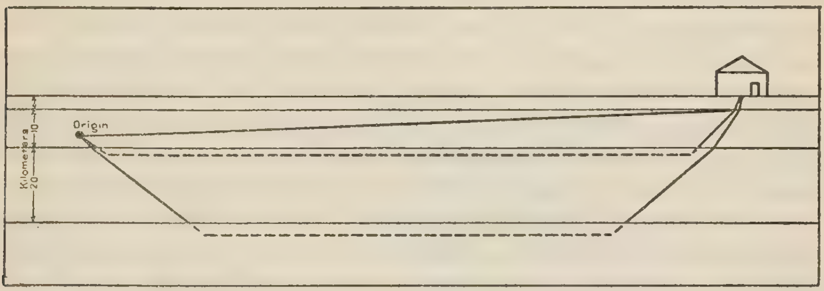

FIGURE 4.—Paths of preliminary earthquake waves through the upper layers of the earth's crust according to Jeffreys. Most of the energy passes along layers of discontinuity and the velocities remain practically constant along such a path

western portions of the United States should meet this requirement. Sieberg [4] gives for a European earthquake depths ranging from 133 to 40 kilometers, according to the method adopted, with 45 to 60 as the most probable. Gutenberg arrives at 50 kilometers as about the average depth for moderately severe earthquakes.

In the case of the Japanese earthquake of September 1, 1923, there were enough records made by strong motion instruments with three components near by so that a simple method, and one independent of time, could be adopted. The observations [5] were so near the epicenter that it could be assumed that the angle of emergence of the waves gave directly the direction of the focus on the assumption of straight-line transmission. The distance of observation points from epicenter ranged from 70 to 132 kilometers. The depths ranged from 35 to 55 kilometers with 48 as the average. This is

[4] Sieberg, Erdbebenkunde.

[5] Mem. Imp. Marine Obs., Kobe, Japan, vol. 1, no. 4, 1924.

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interesting in view of Gutenberg's adopted 50 kilometers. This method becomes uncertain at distances greater than 200 kilometers both because the ratio of depth to distance is becoming small and because straight-line transmission can no longer be assumed. There is still much work to be done on this problem.

When we come to the central region of strong earthquakes, we find conditions of great complexity. Observations by adequate instruments are so few that we are driven to study earthquake effects as the best guide to what has occurred, a method obviously defective. Men under mental stress are not capable of making observations with the impartial attitude of a machine. However, invaluable information is obtained from such reports and when a phenomenon is reported by many witnesses which seems to conflict with the known principles of earthquake wave behavior, a careful investigation should be made. As an illustration, in regions of deep alluvium or of a moderately thick layer of soft material, earthquake waves have been seen to pass over the ground in a manner similar to the ground swell of the ocean. In the case of the California earthquake of 1906, 16 persons in as many different localities reported seeing such waves. Similar reports were made in the case of the Porto Rican earthquake of 1918, and there have been many other examples.

At first thought this might seem not unreasonable, but it must be remembered that while earthquake waves travel at least 2 miles per second, the ocean swell rarely exceeds 65 feet per second. It is therefore difficult to comprehend how we can see the waves pass along. Crests of such waves have been reported as 2 feet above the troughs, but, even if the phenomenon is genuine, the probability is that the height does not exceed 6 inches. It will be interesting to learn the facts by instrumental observation. In some cases a series of parallel cracks in the earth have been found parallel to the crest of the reported waves. Even then the waves may be an illusion due to the effect of the earthquake itself on the observer.

Railroad tracks sometimes afford evidence that strong forces have been at work. In some cases the distortion appears to have been due to shortening, but it is not clear how this shortening has been brought about. No effort has been made to analyze the forces. The directions taken by falling monuments in cemeteries bear witness to the variations in the forces at work. Often the majority will fall in the same directions, but the remainder will fall at an angle with, or even at right angles to, the prevailing direction. There are many striking examples of turning of a monument on its base, or even of different parts of a monument by different amounts, but without fall.

The effects on buildings are of interest. In many cases the destruction is so great or the failure so varied that they are not instructive. Much can be learned, however, from study of selected details. It is, however, very difficult to deduce the actual earth movements in this way on account of the complexity and variation in the stress applied and our lack of knowledge as to just what part of the activity produced given results. But even then much can be learned, and a large part of existing effort to prevent damage from earthquakes has been obtained from the study of damaged buildings. Much work has been done in Japan by the Earthquake Research Institute and other organizations, and buildings are being erected which are expected to resist destruction or even serious damage. The report of the great earthquake of September 1, 1923, contains much valuable information, but is not yet available in English.

The acceleration of the ground movement is the rate of change in its velocity and it appears to be closely related to the destructiveness of an earthquake. While there are many other complicating factors, engineers in designing structures have generally accepted acceleration as the principal element to consider constants in the formulas which are not satisfactorily known. One of the most important of these is the maximum acceleration; without certain knowledge of this, the engineer is not sure of his factor of safety.

We have all sorts of statements as to the relation between acceleration and damage, and the so-called Mercalli-Cancani scale of earthquake intensity is a double scale of equivalents. Engineers are beginning to adopt 0.1 acceleration of gravity for maximum horizontal and 1/20 g for vertical acceleration. In Italy higher values have been adopted up to 1/6 g. This must be considered in the light of the fact that we have few instrumental determinations of accuracy.

There has been no lack of effort to make such determinations. A favorite device consists of a series of small columns side by side so arranged that each will fall when a given acceleration has been reached. The information given by such a device is limited to a single observation with the time of occurrence unknown and we can never be certain whether the last column to fall (that responding to the highest acceleration) has responded to the proper maximum or whether a rapid series of impulses of lower acceleration have not through resonance caused the column to fall.

Other attempts have been made to deduce the maximum acceleration from the fall of objects. Here again we do not know whether there has been a single impulse or the accumulated effect of several. A typical example of the straits to which seismologists and engineers have been driven is the attempt of Bailey Willis to deduce this in-

formation in the case of the Chile earthquake of 1922 from the fall of boundary walls of adobe. Unfortunately, the bottoms of the walls were weathered and somewhat rounded and this vitiated the conclusions. It is obvious that instrumental observations alone will give the true values of the acceleration. Acceleration, however, can not stand alone as the cause of destruction. It is the combination of acceleration, period, duration of the shock, and perhaps the number of periods of strong shock which causes the destruction. Imamura [6] gives an example of an earthquake occurring in March, 1930, in Japan where the recorded acceleration was 0.8 *g*, but the period and duration were both very short and no serious damage was done. It is obvious that records to be useful must give all these factors accurately.

These observations, when made, should be competent to decide the question of the existence of surface waves of considerable amplitude and of low velocity which have been mentioned. It is also important to learn more about the differences in the effects of earthquakes which rupture the surface and those which are of great intensity but too deep to cause such rupture. Of particular interest are the vibrations set up by visible slipping along a fault plane. It would be of great interest to know just what is the difference in the transmission of energy in earthquakes of this type from that in such cases as earthquakes associated with volcanic eruptions in which the energy appears to go out equally in every direction.

Observations of a few strong earthquakes in their central regions will not solve all these and other problems. The possible number of combinations are very great. However, with an effective program the accumulation of information will be steady.

The recent New Zealand earthquake (February 2, 1931) has shown, as have many others, that certain types of earthquake damage are inevitable. Types of construction matter little if the building is directly over a fault line with horizontal or vertical slipping or in the path of a great landslide. If a great tidal wave occurs buildings in its path will be swept away. However, for most earthquakes the number of buildings exposed to these special hazards is not a large proportion, and the most common needs are ability to resist strong shocks and fire prevention. In both these fields there are important possibilities. Earthquakes are no more numerous or more severe than in the past, but the earth is so much more intensively occupied that the risk of important damage is greater than ever before and is constantly increasing.

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[6] Imamura, A., and others, On the recent Ito earthquake, Proc. Imp. Acad., vol. 9, No. 5, 1930.

The problem, then, is prevention of disaster due to moderately severe earthquakes and reduction of damage due to great ones. Engineers are beginning to agree that major structures should be designed with regard to earthquake stress if the history of the region indicates that they are likely to be subjected to such stress. They are recognizing the lack of information and are demanding that more accurate information be obtained.

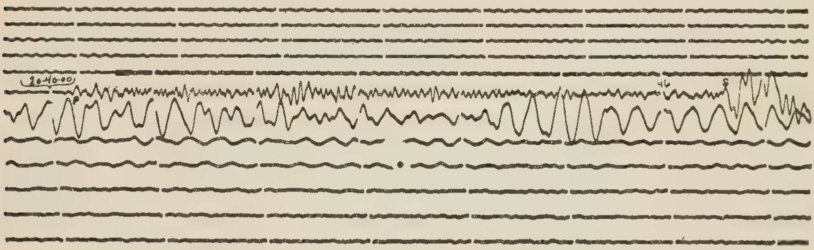

FIGURE 5.—Record made by Wood-Anderson seismometer at Tucson Magnetic Observatory, Tucson, Ariz., on November 18, 1929. Grand Banks earthquake. E.-W. component

It is of particular interest to know that in 1931 Congress provided funds for undertaking this work which will start early in 1932. Suitable plans have been worked out in cooperation with organizations on the Pacific Coast and the first instruments for securing information regarding earthquake motions of interest to

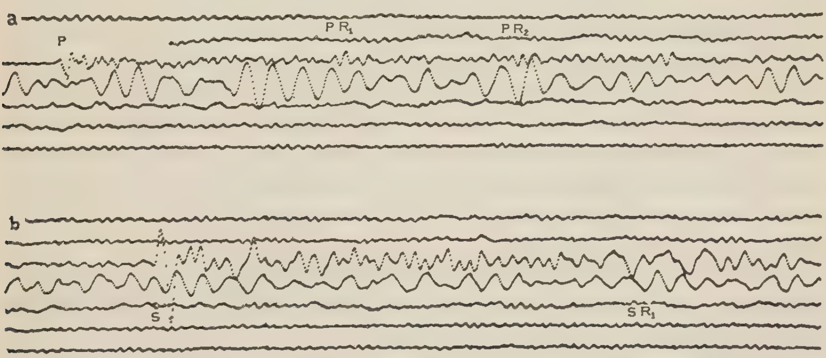

FIGURE 6.—Seismogram recorded by Wenner horizontal component seismograph at United States Bureau of Standards, Washington, D. C.

engineers will be made in this region. This does not mean that this is the only part of the United States where strong earthquakes may occur. In fact, the most severe earthquakes in this country during the past five years have been in the East, but it is a region where earthquakes of severity have occurred in a number of localities and therefore with suitable distribution of instruments earlier results may be anticipated there than elsewhere. Furthermore, the demand

for this work comes from that part of the country where a sentiment of wise preparedness for possible emergency is being developed.

The purpose is to install instruments capable of recording accurately strong earthquake motions in places where history indicates that there is probability of earthquake activity of some intensity. It is regrettable that such instruments were not installed in New Zealand last February when invaluable information could have been obtained. However, instruments of a satisfactory character were not in existence, nor are they to-day, except for several types that have been developed in Japan which are adapted to frequent, strong activity (pl. 8, fig. 2). In this country the Bureau of Standards, the Coast and Geodetic Survey, the Massachusetts Institute of Technology, and the Earthquake Research Laboratory at Pasadena are all at work on the development of such instruments, and it is expected that satisfactory instruments, even if not of the ultimate type, will be available before the end of the present year.

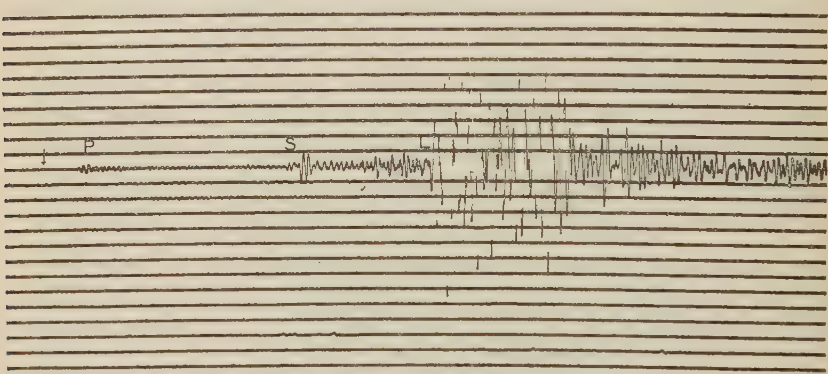

FIGURE 7.—Section of seismogram, actual size, recorded by a McComb-Romberg seismograph, small model, on August 16, 1931, at Washington, D. C. Component, N. 75 E. Time mark indicated by arrow point=11 hr. 45.0 min., Greenwich civil time. Epicenter: 30.0 N., 140.5 W.; southwestern Texas

It would be premature to describe instruments which, though in process of development, have not yet been tested, but a few fundamental principles may be mentioned.

It is not necessary to have elaborate piers separated from the floor of the building, as for teleseismic instruments, but these strong motion instruments may be placed directly on a basement floor or preferably on a block of concrete resting on the floor. The principle by which early recorders were set in motion by the earthquake, long since abandoned because the important earlier and weaker phases were lost, is being revived in different form. With a continuously turning drum and with photographic recording started by the earthquake the objections are met, with resultant great economy of operation.

If we know the acceleration, amplitude, and period, other desired information can be deduced. The proposed instruments will be capable of recording accelerations up to at least 1/5 g and simple devices will also be available which will record accelerations up to the value of g, though with no such complete record as for the instruments just mentioned. The instruments themselves will have to be safeguarded to resist destruction from earthquake.

Earthquakes are in many cases related to movements of the earth's crust which may occur at the time of a severe earthquake or during the interval between great earthquakes. The only satisfactory way to determine such movements is by precise triangulation and leveling repeated at suitable intervals. Much work of this sort has been done in Japan, especially leveling with significant results. In this country triangulation was executed in California after the earthquake of 1906 which determined the local movements. During the last few years, as the result of a special appropriation by Congress, triangulation has been executed in California with connection to undisturbed regions to the east, and the plan includes repetition of the observations from time to time. A similar situation exists in regard to precise levels, though more of this work remains to be done. It has been pointed out by geologists that though practically all of the movement in the 1868 and 1906 California earthquakes was horizontal, geological studies indicate prevailing vertical movements in the past.

This work has required high accuracy, and it has been strengthened both by complete adjustment of all the triangulation of the western half of the United States and also by the establishment of Laplace stations in the region of the special triangulation. These are stations where complete astronomical observations are made and these are combined with the geodetic observations in such a way as to improve the azimuths of lines and consequently the geographical positions of points throughout the scheme. While there are a few cases of large movements, there seems little doubt that at the Point Reyes station there has been horizontal movement of the station from its former position of 10½ feet, implying a shift of this amount of the earth's crust. This is the greatest amount observed anywhere in California.

The Japanese have added another type of investigation that they have found very useful. Even before the days of instrumental observation, as far back as 1793,[7] the inhabitants of a coastal village noticed a sudden movement of the shore beneath their feet, and assuming that it meant the arrival of a tidal wave they rushed to the hills. Nothing occurred for four hours. Then came a great earth-

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[7] Topographical changes accompanying earthquakes or volcanic eruptions, Publ. Earthq. Investig. Comm. in Foreign Languages, No. 25, Tokyo, 1930.

quake and tidal wave. This phenomenon has been observed to a lesser degree in other earthquakes, and the natural assumption is that the surface of the earth tilts just before the earthquake. In four earthquakes the intervals have varied from one-half to four and one-half hours. Recently instrumental observations have been made of the tilt of the ground which confirms the earlier observations and indicates that in Japan, at least, the tilting of the ground is significant. This does not refer to local tilts due to temperature which the tilt compensation seismometer eliminates, but it is a long-period tilting of the ground in regions subject to severe earthquakes with rapid tilting just before the earthquake. If it can be definitely established that this is common to all earthquakes in Japan, even when the amount is less than can be readily perceived, it may be possible to give an advance notice of a few hours which might be invaluable. The Japanese have developed a tiltmeter, and another instrument for this purpose has been designed at the United States Bureau of Standards, but has not yet been constructed. It is important to learn whether this phenomenon is peculiar to Japan or any other region where there is block faulting on a large scale or whether the same thing will be observed in this country.

My purpose has been to show that a program of earthquake investigation is being developed which, when added to the already well organized plan, will fill important gaps in present knowledge. Stress has been laid on fundamental principles, instruments, and methods, and this serves to emphasize that we are still in a stage when these are the all-important things. We are beginning to utilize the records to find out facts about the earth, but there is great room for expansion in this field. There are two great fields of investigation—that treating the earth as a whole, or dealing with a substantial portion of its crust such as the area of the United States, and the local investigation as exemplified by the investigations in California under the auspices of the Carnegie Institution of Washington, the California universities, and other organizations, the investigations in the Mississippi Valley under the auspices of St. Louis University and the National Research Council, and the plan of the Coast and Geodetic Survey for cooperative observations chiefly for the benefit of the engineer.

The studies with regard to the United States as a whole are carried on by the National Government through the Coast and Geodetic Survey with the cooperation of the Weather Bureau, the Geological Survey, the Bureau of Standards, and the National Research Council, the members of the Jesuit Seismological Association, and the universities and colleges in different parts of the country. The eventual aim is to keep informed in regard to the elastic condition of the earth's crust.

Many are thinking of the future of seismology. I am going to close by quoting the views of Capt. R. S. Patton, Director of the

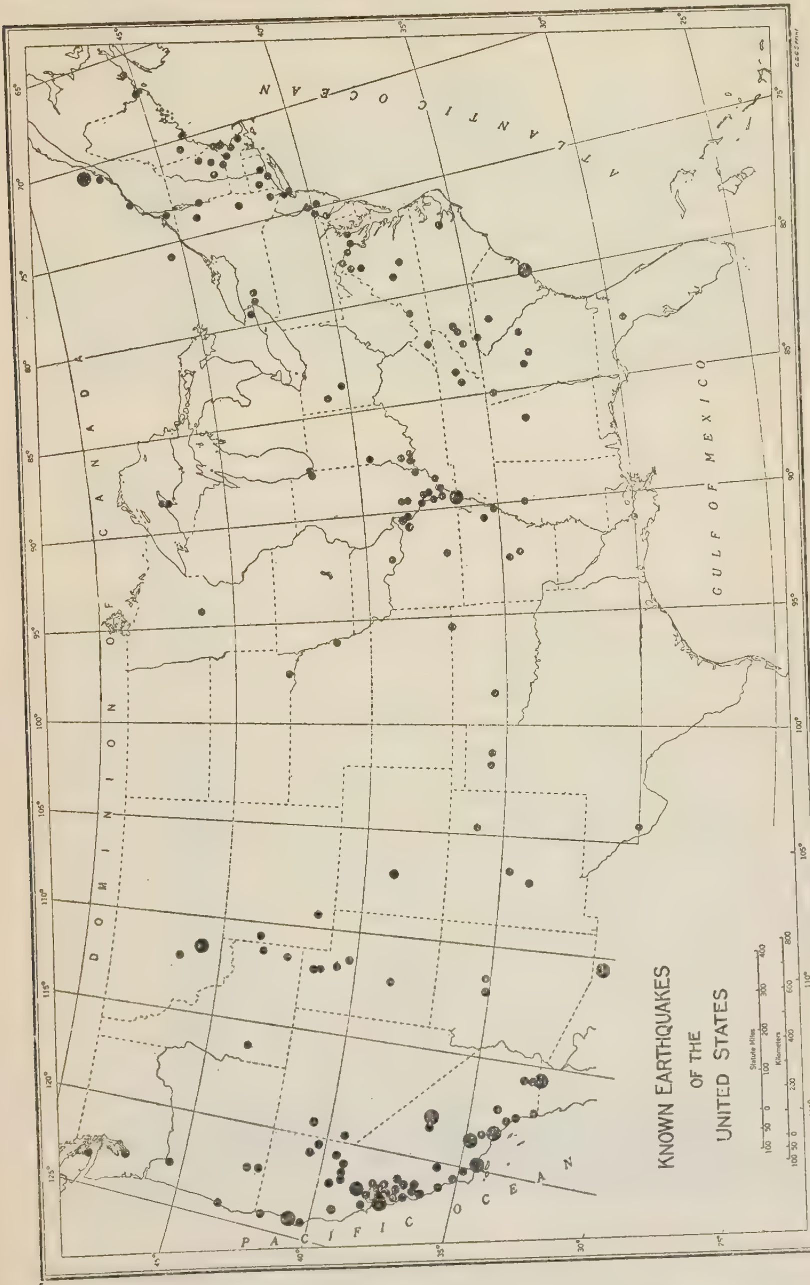


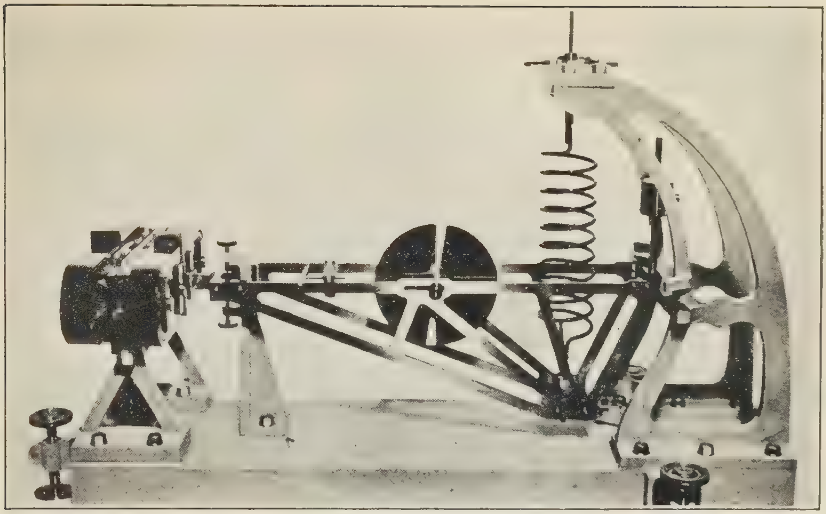
FIGURE 8.—Known earthquakes of the United States

Coast and Geodetic Survey, who, in addition to his administrative relation to the work, has a strong personal interest in the future

development of seismology so as to meet all needs. In a recent statement he said:

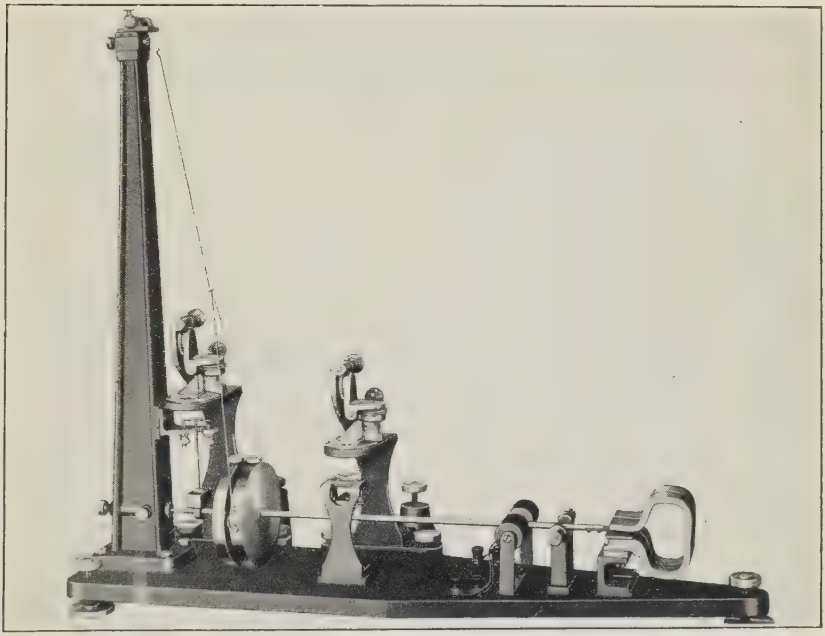
I feel that in recent years we have made most gratifying progress in our attack upon the problems of seismology in the United States. I can not too highly commend the little groups of men by whom that progress has been accomplished. They have not only worked untiringly individually, but their cooperation with one another has been splendid.

But I also believe, first, that there is need for increased future effort, and, second, that any such increase will necessitate a more formal means of coordinating the activities of the various participating groups. There will be particular need to clarify, and to dovetail together, the respective fields occupied by the two general groups consisting, on the one hand, of the geophysicists, concerned with the pure science of seismology, and, on the other hand, the engineers, architects, and others who are concerned with earthquakes because of their potential menace to life and property.



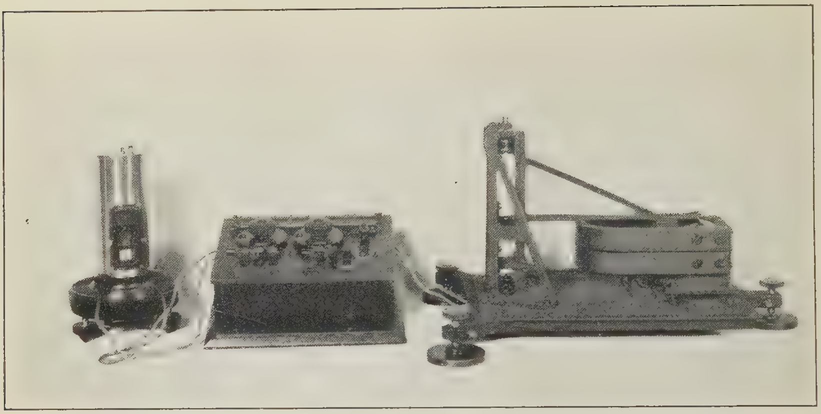
1. GALITZIN VERTICAL COMPONENT SEISMOMETER

This consists essentially of a heavy mass, known as the steady mass, mounted on an arm which is pivoted to a rigid column in such a manner that the boom will move freely in a vertical plane. The free end of the boom carries a series of coils which move in a strong magnetic field as the boom oscillates. The terminals of this series of coils are connected to a sensitive galvanometer. As the coil moves in the magnetic field, a current of electricity is generated in the circuit which deflects the galvanometer by an amount depending upon the amplitude of the motion and the frequency. The ground movements, highly magnified, are recorded photographically by reflecting a beam of light to a photographic recorder described under Plate 2, Figure 2.



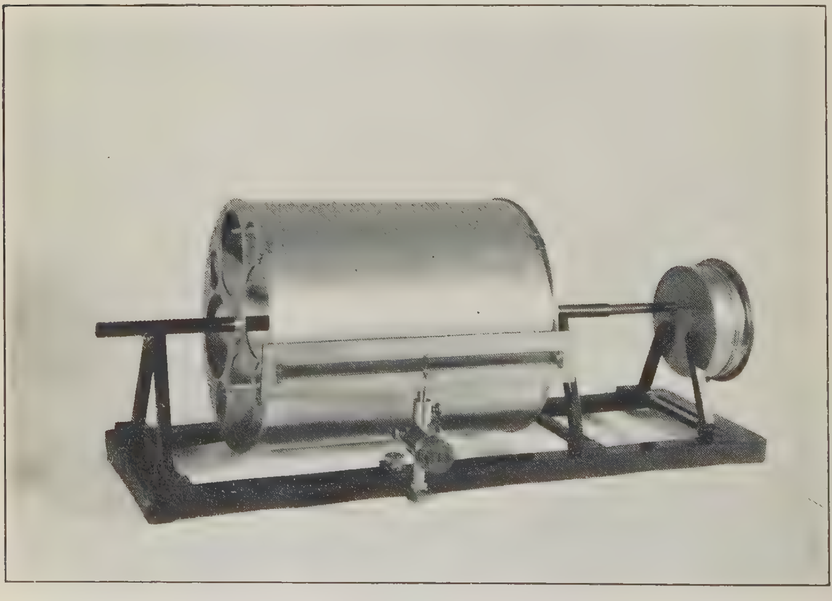
2. TILT-COMPENSATION SEISMOGRAPH, MCCOMB-ROMBERG TYPE

In order to eliminate the troublesome effects of slow (daily) tilting of the ground due to temperature changes, the steady mass of this instrument is coupled to the multiplying lever through oil. Except for relatively rapid oscillations the mirror of the multiplying lever tends to remain in a horizontal position and the effects of slow tilting are adequately eliminated. The operating principle of the pendulum depends upon the inertia of the steady mass. This instrument is designed to register only horizontal motion.



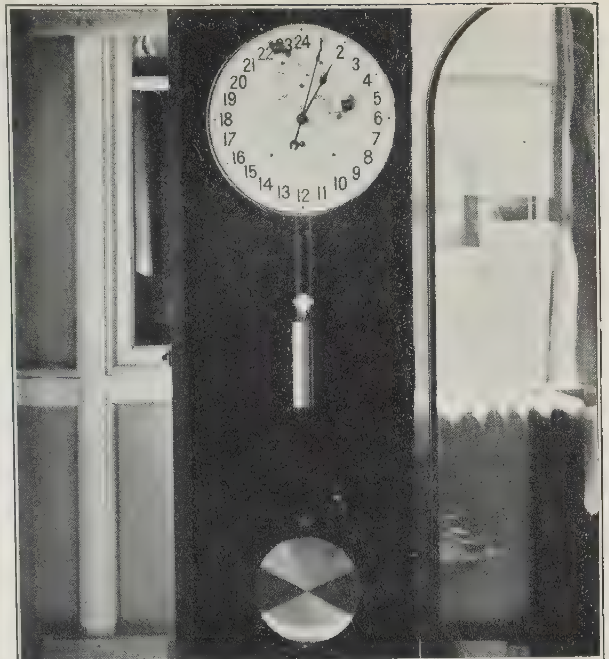
1. WENNER HORIZONTAL COMPONENT SEISMOMETER AND EQUIPMENT

As in the Galitzin seismometer the boom of this instrument carries a coil which moves in a permanent magnetic field as the boom oscillates. The circuit is closed through a sensitive galvanometer carrying a mirror for use in photographic registration. Suitable resistances are placed in series with the coils and also in parallel with each branch of the circuit. The latter determine the degree of damping of seismometer or system. In this instrument the coil of the seismometer moves in a radial magnetic field; that is, the axis of the coil is coincident with the axes of the pole pieces, one pole piece being within the coil and the other without.



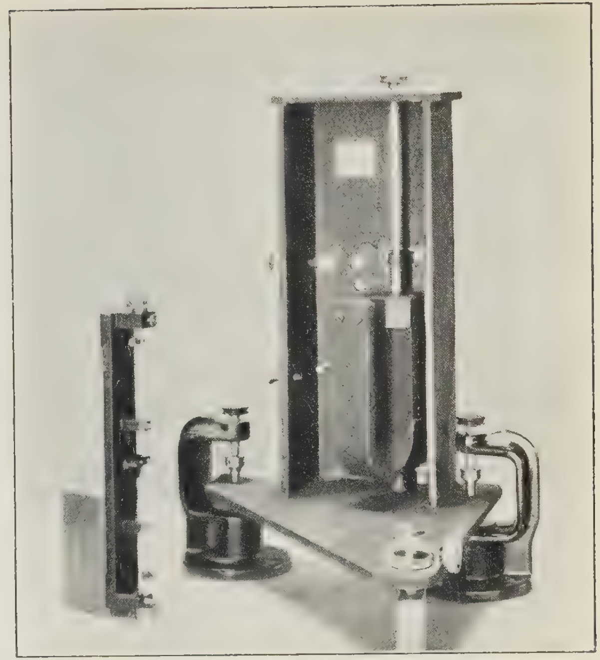
2. SEISMOGRAPHIC RECORDER, PHOTOGRAPHIC

This recording drum carries a sheet of photographic paper upon which a beam of light as reflected from a seismometer or galvanometer is brought to focus. The drum, and with it the paper, is driven on its axis at a speed of 15 to 60 millimeters per minute and at the same time is translated along its axis at a speed of about 5 millimeters per minute. The resulting record after photographic development in the usual manner is called a seismogram.



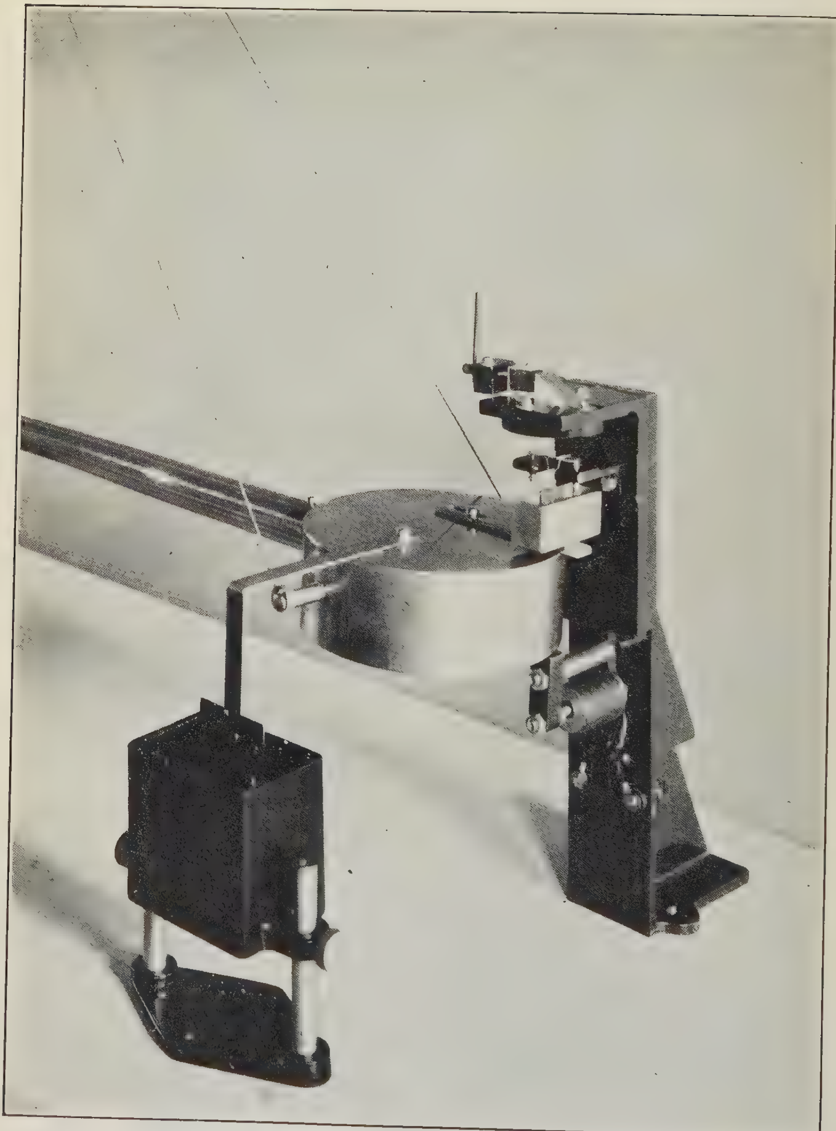
1. PENDULUM CLOCK FOR MARKING TIME ON SEISMOGRAMS

It is essential that time marks be placed on seismograms at frequent intervals, usually every minute. This clock is provided with equipment which closes an electrical circuit at desired intervals and this circuit operates other devices which place the desired marks on the seismogram photographically.



2. WOOD-ANDERSON TORSION SEISMOMETER WITH SUSPENSION REMOVED

In this instrument the steady mass consists of a very small cylinder or vane attached along one edge or element to a fine tungsten filament held in a vertical position under slight tension. The filament acts as the axis of rotation of this small horizontal pendulum. A mirror is attached to the upper part of the steady mass for use in photographic registration of ground movements to which the system is very sensitive.



MULTIPLYING LEVER, BRACKET, AND DAMPING VANE OF MCCOMB-ROMBERG SEISMOMETER

See description under Plate 1, Figure 2.

LOCATION OF AN EPICENTER ON AN 18-INCH GLOBE AT THE UNITED STATES COAST AND GEODETIC SURVEY, WASHINGTON, D. C.

Each seismograph station is prominently marked on this globe. The distances from each seismograph station of record to the epicenter are laid off on the globe. With a pair of compasses arcs are described on the globe with seismograph stations as centers and chords corresponding to epicentral distances as radii. The intersection of these arcs gives the position of the epicenter, the accuracy of the position depending upon the accuracy of the interpretation of the seismogram and the accuracy of travel-time tables.

1. DESTRUCTIVE EFFECTS OF JAPANESE EARTHQUAKE OF 1923, YOKOHAMA

2. SUBSIDENCE OF THE GROUND WITH CONSEQUENT TILTING OF BUILDINGS IN THE VICTORIA BATTERY, PORT ROYAL

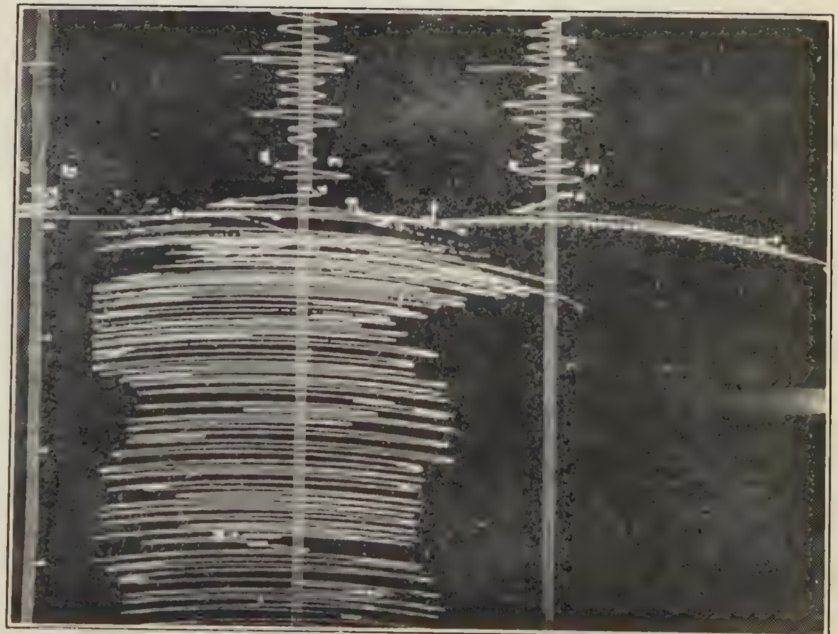
The kink in the railway track is over a fault.

Photograph by United States Geological Survey

DERAILMENT OF TRAIN OF CARS DUE TO CALIFORNIA EARTHQUAKE OF 1906

Courtesy of E. A. Hodgson

1. DISPLACEMENT OF CEMETERY MONUMENT DUE TO EARTHQUAKE



Photograph by Bureau of Social Affairs, Japan

2. SEISMOGRAM MADE AT TOKYO OF GREAT EARTHQUAKE OF SEPTEMBER 1, 1923

Magnification one-half.

GROWING PLANTS WITHOUT SOIL

By Earl S. Johnston
Division of Radiation and Organisms, Smithsonian Institution

[With 4 plates]

Over 300 years ago Johan Baptista van Helmont carried out a very simple and interesting experiment at Brussels. The following is a record of the experiment as given by Russell:

> I took an earthen vessel in which I put 200 pounds of soil dried in an oven, then I moistened with rain water and pressed hard into it a shoot of willow weighing 5 pounds. After exactly five years the tree that had grown up weighed 169 pounds and about 3 ounces. But the vessel had never received anything but rain water or distilled water to moisten the soil when this was necessary, and it remained full of soil, which was still tightly packed, and, lest any dust from outside should get into the soil, it was covered with a sheet of iron coated with tin but perforated with many holes. I did not take the weight of the leaves that fell in the autumn. In the end I dried the soil once more and got the same 200 pounds that I started with, less about 2 ounces. Therefore the 164 pounds of wood, bark, and root arose from the water alone.

The experiment is simplicity itself and may be repeated by anyone. The language describing it is clear and lacks the many technical terms which are common in modern descriptions of experiments. In spite of the many good qualities commending this famous old experiment, Van Helmont's conclusion is illogical and incorrect. As we shall note directly, the 164 pounds of wood did not arise from the water alone.

If he had taken the young tree and dried it, thus driving off the water, its weight would have been reduced 40 to 50 per cent. If he had then burned this dried wood, ash or noncombustible material would have remained, though but a small fraction of the final weight he recorded.

Almost half the weight of woody plants can be attributed to the water contained in the plant cells and tissues. The other half consists mainly of organic matter which can be burned, forming carbon dioxide, one of the gases in the air. If approximately 50 per cent of the plant can be returned to the air as carbon dioxide, it seems reasonable to suppose that this gas might have been withdrawn from the air

by the plant during its growth. Van Helmont had neglected to consider the air as a very important source of material for plant food. Since his day, scientists have discovered that plants absorb carbon dioxide from the air, and, by means of the energy of sunlight, unite it with water to form sugars and starch. This process is known as photosynthesis. From these manufactured substances the plants build more complicated food materials which are used in their growth and reproduction.

The ash that remains after the water and combustible materials have been driven off by heat should not be overlooked. Although the amount of ash is small in comparison to the other materials making up the plant structure, it contains several very important mineral elements that are vital to the growth and vigor of the plant. The more commonly known elements are calcium, phosphorus, potassium, magnesium, and sulphur. These are some of the elements that form the essential ingredients of fertilizers. More than 30 elements have been found in the ash of plants. The amounts of some elements such as chloride, sodium silicon, and iodine vary greatly in different types of plants. Even traces of zinc, tin, lead, silver, and copper have been found. Scientists do not at present know if all these elements are necessary for the growth of plants, but they are finding that minute traces of some elements, such as boron, manganese, and zinc are just as essential as those usually mixed to form commercial fertilizers.

As early as 600 B. C. it was thought that plants obtained all their food from water. It is not water alone that the plant takes through the roots, but the mineral elements dissolved in it. Even to-day many people are surprised to hear that solid particles of fertilizers are not absorbed by plant roots. These mineral substances must first be dissolved in the soil water before they can pass into the plant through the delicate root membranes. In fact the solid soil may be dispensed with and the roots surrounded by liquid only. However simple the technique of growing land plants with their roots in water may now be, it was not until 1699 that there were any published records of such plants grown in water cultures. Woodward grew spearmint, potatoes, and vetch in water from a conduit, in river and spring water, as well as in rain and distilled water. His purpose was to determine whether the water itself or what it contained in the way of dissolved matter was the nutrient material used by plants. He concluded that the water was the carrier of the necessary "terrestrial matter."

The next important step was for man to add artificial terrestrial matter to pure or distilled water and thereby determine which elements were essential to good plant growth and which were not. Then followed a series of experiments by plant investigators to determine

the relative amounts of these essential elements that would give the best growth. Years of practical agricultural experience had taught man that plants needed nitrates, phosphates, and potash in the soil. By many trials they also found that some proportions were better than others. Science is now showing by means of water culture studies why some of the earlier practices worked out so well. By this method man is endeavoring to find out the exact uses made of the different elements by plants.

A natural question which arises is, why should investigators prefer to grow plants in water containing dissolved chemicals instead of putting the same chemicals in the soil where plants grow normally? A brief discussion of some of the difficulties involved in the use of soil will show why water cultures are preferable in experiments where all the conditions influencing plant growth are rigidly controlled. Physically, the soil is made up of rock particles varying in size and shape which are usually mixed with organic material. The amount of water that soils hold depends on these properties. Water easily runs through a loose soil. In a closely packed soil water movement is slow. In experiments where several plants are to be grown with their roots in exactly similar media, it is at once realized how difficult the problem is of potting a number of plants in soil so that all of them may be rooted among particles of the same size and shape, and similarly packed. When the packing, or arrangement of particles, is different, it is found that the capillary water films in the soil as well as in the air spaces are altered. All these different physical factors would be possible sources of error in an otherwise accurately controlled experiment.

The problem of obtaining two soils that are exactly alike in their chemical composition is even more difficult than that of securing two that are similar physically. Even a slight difference in the chemical composition of two soils may bring about a marked difference in plant growth. A single illustration will serve to show the importance of this consideration where quantities as small as one part of a certain element in 2,000,000 parts of the soil water makes enormous differences in plant growth. Boron, a substance found in boric acid and borax, and until recently, not seriously considered important in plant growth was the element involved in this work. Pure quartz sand was used instead of ordinary garden soil as the medium for growing a number of potato plants. The sand was watered with a solution containing all the elements then considered necessary for growth. New glazed earthenware crocks were used to hold the sand. In the first two series of experiments the plants grew very well, but in later work they became unhealthy and usually showed early death of the stem tips. Later when the importance of small traces of boron was recognized, the real explanation of the poor growth was obvious.

When the crocks were new the plants obtained a sufficient supply of boron from the glaze. Later this element was more difficult for the plants to obtain as the available supply became exhausted.

A simple experiment clearly brought out these facts. The same crocks were again used, as well as sand from the same source used in the earlier experiments. However, a very small amount of boron was dissolved in the solution used for watering half the plants. This amount was almost inconceivably small, being one part of boron to 2,000,000 parts of the solution. The potato plants had little difficulty in detecting and using this minute quantity of boron. The difference in growth is clearly seen in Plate 1. Imagine to what extent a man would be nourished by eating pea soup with one pea to each 132 gallons of water. Yet there are minute quantities of certain substances just as important to man as boron is to plants. Certain glands manufacture traces of interesting chemical compounds called hormones which stimulate or retard the growth of animal tissue. The discovery of iodine in the thyroid was followed by the isolation of thyroxine, a stable iodine-containing hormone.

Too great quantities of certain elements in the soil are just as harmful to plants as too small amounts. Slight differences frequently bring about enormous growth responses. To obtain two or more pots of soil that contain exactly the same amounts of all chemical elements affecting plant growth is a herculean task. Even if two such pots of soil were obtained it would be even more difficult to determinate accurately the amounts of all the chemicals used by the plants. It is hence easy to see that soil cultures are not very good media for growing plants in accurately controlled experiments. For these reasons and for the simplicity of handling and controlling the elements, water cultures are being used more and more where exact information of the plant's growth and behavior is desired.

Water-culture experiments, or those in which plants are grown in mineral nutrient solutions made by dissolving pure chemicals in distilled water, have furnished science a means of distinguishing the useful or essential plant-food elements from the useless or nonessential. It is true that chemical analysis demonstrates the presence of many elements in plant tissues. It is poor reasoning, however, to claim they are all essential. Plants as well as animals take into their tissues certain nonessential substances along with the essential. The late Prof. Cyrus Hopkins gave to his students a mnemonic system whereby they could easily remember the then supposed essential elements for plant growth. It read "C. Hopkins cafe, mighty good." When expressed as chemical symbols it appears as follows: C. HOPKNS, Ca Fe, Mg, which represent the elements carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulphur, calcium,

iron, and magnesium. Boron, manganese, and undoubtedly several more elements should be added to the list.

In what forms or chemical compounds can these elements be "fed" to the plants? There are numerous combinations of these elements, but perhaps the salts most frequently used are calcium nitrate, $Ca(NO_3)_2$; magnesium sulphate, $MgSO_4$; monopotassium phosphate, KH_2PO_4; potassium nitrate, KNO_3; ammonium sulphate, $(NH_4)_2SO_4$. Iron may be supplied in any one of several compounds such as tartrate, citrate, phosphate, or sulphate. A trace of boric acid and manganese should be added where all other materials are of the highest purity. To be sure, certain plants require larger amounts of a given element than others and this same thing is true of a given plant at different stages of its development, but in spite of such limitations it is rather surprising to find considerable variation in the concentrations and proportions of these salts that produce good growth.

Almost every original investigator in the field of plant nutrition has devised a particular solution of his own. The result is that there are many formulae for making plant-nutrient solutions, each of which has some good points. The chief purpose of any of these solutions is to give the plant the elements that it needs for its growth in a readily soluble form. The ones obtained from the soil in largest amounts are nitrogen, phosphorus, potassium, calcium, and magnesium. Many different nutrient solutions have been made from various combinations of these elements. That proposed by Sachs was the first so-called standard solution. Perhaps none has been more generally used than the one devised by Knop, which is made up of the following salts by weight: Four parts calcium nitrate, one part potassium nitrate, one part magnesium sulphate, one part either mono or di potassium phosphate, trace of iron.

Knop's solution was greatly improved by Tottingham for the growth of wheat and then simplified by Shive to a solution composed of the following volume-molecular proportions of but three salts:

KH_2PO_4	0.0180 m
$Ca(NO_3)_2$	.0052 m
$MgSO_4$	.0150 m

To be sure, iron was needed and was supplied in a very small amount, as $FePO_4$. Six of the essential ions—K, Ca, Mg, PO_4, NO_3, and SO_4—used by plants in the greatest amounts were found in Shive's simple formula. When very pure salts and distilled water are used it is necessary to add small amounts (mere traces) of other necessary elements. Our more recent knowledge of plant nutrition

calls for a more complicated solution than the three-salt one. A solution which the writer found to be good for growing tomatoes contained the following ions expressed as parts per million parts of water used:

Calcium	(Ca)	200
Magnesium	(Mg)	60
Potassium	(K)	78
Nitrate	(NO_3)	620
Sulphate	(SO_4)	290
Phosphate	(PO_4)	74
Manganese	(Mn)	1
Boron	(B)	1
Iron	(Fe)	Enough to keep plants green.

The excellent growth made by the plants in this solution can be seen in Plate 2.

Each ion included in the above list exerts a definite influence on the growth of plants. So characteristic is the effect of the omission of a single element that the plant itself frequently serves as an index of the element it lacks for normal growth. Again using the tomato plant as an example, a healthy leaf and one taken from a plant suffering from "potash hunger" are contrasted in Plate 3. An insufficient amount of potassium results in a yellowing of the older leaves, which later are covered with brown spots. On the other hand, phosphorous deficiency brings about a deepening of the green color of the leaves, and in severe cases the lower leaf surfaces become distinctly purple and the stem grows out slender and sharply pointed. With extreme calcium deficiency the growing points of the stem soon die and become dry.

A common method for growing plants in a nutrient solution is, first, to germinate the seeds between layers of moist filter or blotting paper kept in a glass dish and covered to conserve the moisture. When the roots grow to one-fourth to three-fourths of an inch in length these seedlings are transferred to a germination net. Two pieces of paraffined cotton fly netting are stretched and fastened over a suitable dish. It is well to separate the pieces of netting from each other by a piece of bent glass tubing one-fourth of an inch in diameter. The dish is then filled with water and the roots of the seedlings carefully inserted in the meshes of the netting. During the subsequent growth of the seedlings tap water is allowed to flow through the dish. After the seedlings have reached a height of approximately an inch they are transferred to the culture solutions. Each culture contains one or more seedlings supported by means of a little cotton in holes of paraffined flat cork stoppers, which fit into the culture jars containing the nutrient solution. The

jars used are frequently of the " Mason " type and should be wrapped with heavy paper to exclude most of the light from the roots. This covering prevents algae from growing in the solution.

Recently a very interesting series of experiments has been completed by Dr. J. E. McMurtrey, of the United States Department of Agriculture, on the mineral deficiency symptoms of the tobacco plant. The nutrient solutions he used were so devised that one element could be omitted without changing the amounts of the other elements. The general appearance of these plants, each of which suffered from an insufficient amount of an essential element, is shown in Plate 4, together with a tobacco plant grown on a complete mineral diet. In connection with these experiments, a key has been prepared which gives promise of having considerable value in the diagnosis of certain malnutritional diseases of the tobacco plant.

The division of radiation and organisms of the Smithsonian Institution has initiated certain types of research in which extremely accurate measurements are being made of several fundamental plant activities. In one experiment the absorption of carbon dioxide by the plant is being studied under accurately controlled conditions. It is highly desirable that the plants be grown in a medium which can be better controlled than soil. In other experiments the effect of various light intensities and wave lengths on the growth of plants is being investigated. Here again soil can not be used because of errors it would introduce into the experiment. For the reasons pointed out in the foregoing discussion the plants used in these accurately controlled experiments are grown in nutrient solutions made by adding the proper inorganic chemical compounds to distilled water.

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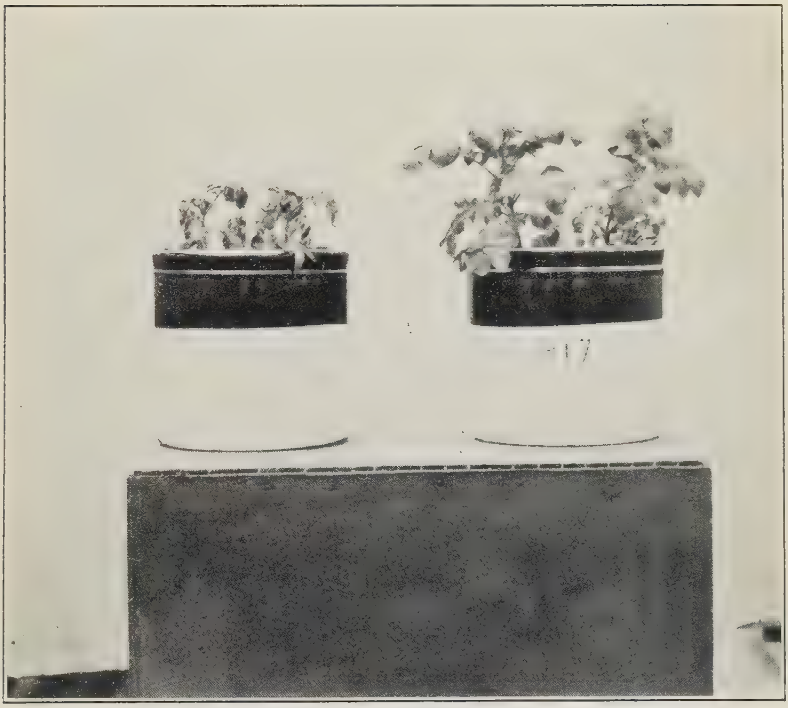

POTATO PLANTS GROWN IN SAND CULTURES TREATED WITH BORON-DEFICIENT SOLUTION (LEFT) AND WITH A SIMILAR SOLUTION TO WHICH A SMALL AMOUNT OF BORON HAD BEEN ADDED (RIGHT)

TOMATO PLANTS GROWN TO MATURITY IN NUTRIENT SOLUTION

TOMATO LEAF SPOTTING (LEFT) DUE TO POTASSIUM DEFICIENCY, COMPARED WITH NORMAL LEAF (RIGHT)

Courtesy of Department of Agriculture

TOBACCO PLANTS SHOWING VARIOUS DEFICIENCY SYMPTOMS

Variations in the appearance of tobacco plants grown in nutrient solutions deficient in the following elements: 1, nitrogen; 2, phosphorus; 3, potassium; 4, calcium; 5, magnesium; 7, boron; 8, sulphur; 9, manganese; 10, iron. All these elements are present in number 6.

SOME ASPECTS OF THE ADAPTATION OF LIVING ORGANISMS TO THEIR ENVIRONMENT [1]

By H. S. Halcro Wardlaw

Our interests as members of this society lead us to consider the relation of living things to their environment from many points of view. We are on the whole, perhaps, more usually concerned with the morphological aspects of this relation, but in this portion of my address I wish to direct attention to certain chemical relationships which subsist between the living organism and its surroundings. After all, the chemical constitution of bodies may be regarded merely as a more intimate expression of their morphology, as an expression involving smaller units than those which are commonly studied by visual examination. And in considering the material relationships between a living organism and its environment we can not ignore the relationships involving exchanges of energy. The conditions of the former are to some extent determined by the requirements of the latter. A survey of this kind would involve the discussion of a wide range of questions. I wish to refer only to one or two of these upon which biochemical information appears to have thrown light, and to discuss one or two examples where adaptations have more obviously been brought about by chemical adjustments.

The thesis which I wish to submit to you may be expressed in two statements: That the changes which living organisms have undergone in adapting themselves to their environment have had as their object the maintenance unchanged of certain essential characters, and that the organism which has most successfully adapted itself to its surroundings is that which has acquired, to the greatest extent, the power of adapting its environment to its needs.

The most bewildering diversity of forms is met with among living things. All these variations of structure may, no doubt, be regarded as adaptations of one kind or another to the various environments in which the different organisms are to be found. It will be as well, therefore, to make clear at the outset what I wish to be understood by

[1] Reprinted by permission from the Proceedings of the Linnean Society of New South Wales, vol. 55, pt. 1, No. 227, Apr. 15, 1930.

my use of the phrase "adaptation to environment," and then to go on to see whether any common factor can be found for the superficially diverse means by which the living organism seeks to attain this adaptation, before discussing any particular examples of adaptive mechanisms.

By the term environment I mean that portion of its surroundings with which an organism can enter into exchanges of matter and energy. The limits of the environment may be hard to define and will depend upon the particular exchanges which are being considered. In the more complex organisms one part may be the environment of the rest.

I shall use the term "adaptation" as implying broadly any means by which an organism is enabled to survive in its surroundings, not as an individual but as a species. The term so understood means not merely the ability to survive, but the ability to survive without alteration of certain characters. A moment's reflection will show that, by this criterion, we have no convincing evidence that any living organism has yet proved itself to be completely adapted to its environment. On every hand evidence is daily being brought to light of species which have become extinct, and yet the members of every living species must have descended, in unbroken succession, from individuals of one or other of those extinct species. Those transient species were obviously not completely adapted to their surroundings, but there was within the living matter of the individuals which composed them, some more effective type of adaptation which has enabled it to survive the impermanence of its external form.

The extinction of so many species has been due, not so much, perhaps, to their inability to adapt themselves to their surroundings, as to their inability to make their adaptions quickly enough to keep pace with their changing environment. For, during the ages which have passed since living forms first made their appearance, the nature of their environment has, no doubt, altered as profoundly as have the living organisms themselves.

Even the simplest living organism seems to be much more complex than any inanimate system of which we have detailed knowledge. But there is no valid reason for supposing that processes other than those which are described as physical or chemical play any part in their fundamental reactions. We may, therefore, expect the behavior of the living organism to show many similarities and analogies to that of inanimate systems in their relation to their environment. On the other hand, there are what at present seem to be rather characteristic differences between the two types of system, although, on close analysis, these distinctions become hard to draw.

A general property of inanimate physical systems is their tendency to reach a state of equilibrium, that is, they tend to reach a state in which exchanges of matter and energy between the various parts of the system, and between the system and its surroundings are no longer apparent. It is true that it may be possible to demonstrate that fluctuations in the state of different parts have not entirely ceased in a system which has reached this condition, but these changes which still continue do not lead to any gross or permanent redistribution of matter or energy.

The same property which makes any physical system tend to reach a state of equilibrium, will also resist any agency which tends to disturb this state. If an attempt is made to change such a system in any way the system will react so that the change produced is not as great as it would have been if such a reaction had not taken place. For example, if a volume of gas be heated at constant pressure it will expand, and in expanding it will cool, so that the total rise of temperature will not be as great as it would have been had the gas not expanded. This system resists the rise of temperature due to heating. Again, many substances, when they are dissolved in water, cause the temperature of the resulting solution to fall. But these substances are less soluble in the colder water, so that less will dissolve than would have if the temperature had not fallen. The system resists the change of concentration caused by the substance going into solution. This behavior is known as the principle of Le Chatelier.

The reaction of a living organism to changes of its environment is not, however, limited to that which would take place according to the principle of Le Chatelier. In the first place a living organism is continually expending energy, and so prevents itself from ever attaining a state of equilibrium with its surroundings. Further, it is provided with regulatory mechanisms which not merely resist changes due to alterations of environment, but which are able to neutralize, even to reverse, their effects. To this property of living things Cannon (1929) has applied the term "homeostasis."

Some of these regulating mechanisms are remarkably efficient. Their object is to maintain unchanged any system of which they are a part. But no such mechanism, however perfect it may be, can render an organism completely independent of external changes. Some response to these changes, however small that response may be, is necessary to set the adjusting mechanism in action, and this mechanism, once set in motion, will not cease to act until the condition aimed at is overshot, no matter how slightly. Such an effect is common to all governing mechanisms. All that they can do is to insure that the variations imposed upon the organism by a changing

environment shall be restricted within certain limits. The more effective the mechanism is, the closer together will these limits be.

Broadly speaking, we may say that the living organism first protects itself against the variations of its surroundings by placing barriers between itself and its environment. The process of encystment and the formation of spores are what appear to be simple examples of this type of reaction which are shown by very simple organisms. Even more highly developed organisms make use of devices of this kind at some stage of their life histories, as in the formation of seeds by plants.

There is no doubt about the effectiveness of such a mechanism for protecting an organism against unfavorable changes of its environment. The extreme difficulty with which the spores of certain microorganisms are destroyed, even by the most drastic treatment, is well known. The tenacity with which the seeds of certain plants retain their viability has been demonstrated by Cambage (1928), who showed that seeds of *Acacia melanoxylon* were capable of germination after 10 years' soaking in sea water. In its simplest form, however, a protective mechanism of this kind imposes severe restrictions upon the organism using it. At times such an organism must purchase its survival by an almost complete suspension of its vital activities. The mechanism can do no more than protect the organism from destruction by extremes of variation in its environment, and appears to display the phenomenon of adaptation in its crudest form. It is a regulatory mechanism which permits of wide variation in the rate at which the organism is able to carry on its activities. Except for this power of passive resistance, an organism limited to this kind of adaptive mechanism is still very largely at the mercy of its environment.

Another way in which an organism may place a barrier between itself and certain parts of its surroundings is by removing itself from those parts. It is able to do this when possessed of the property of motility which is shown even by some of the most primitive forms of life. As an adaptive mechanism, motility in many ways is a distinct advance beyond processes similar to encystment. The motile organism is able to make use of one part of its environment to protect itself against another. Instead of erecting about itself, when conditions become unfavorable, barriers composed of its own substance, it is able to place parts of its environment between itself and those conditions.

It is evident that the freedom of an organism possessing motility must be much greater than that of similar organisms without this mechanism. Its effect is to render unnecessary many of the variations of activity to which the nonmotile organism must be subject,

by avoiding many of the occasions on which those variations would occur. It is an adaptive mechanism which avoids many adaptive modifications on the part of the organism. In addition it is capable of being much more selective in action than a mechanism which withdraws the organism from a condition of interchange with its environment. The working of this mechanism is seen most clearly perhaps in the tropisms which many of the more primitive living forms display. The movements of the more complex organisms do not always bear such an evident relation to the effects of environment as do those of the simpler. They are complicated as a rule by the simultaneous action of many other adaptive mechanisms. The large-scale movements, however, even of the higher animals, such as migrations, are sufficiently analogous to tropisms to suggest that they may be the results of some common underlying mechanism.

An organism possessed of the property of motility is considerably more independent of its surroundings than an organism limited to the type of adaptive mechanism first discussed, but its chances of survival are not necessarily greater. While it does survive, however, its vital activities are likely to be much less subject to variation than those of an organism whose only protection is quiescence.

Although this mechanism shows a great advance over that previously discussed, its effectiveness is still decidedly limited. It is, no doubt, adequate for those simple organisms whose normal environment is not subject to much simultaneous variation in several components. Such a mechanism is likely to break down, if not assisted by other regulatory devices, when the organism is faced with concurrent changes of different factors of its environment. Removal of the organism from a portion of its environment unfavorable in one respect may deprive it of conditions which may be favorable in other respects. An organism restricted to this type of adaptive mechanism, or even possessing it in addition to the power of becoming encysted, would often find itself in a dilemma.

PRIMITIVE RELATIONS BETWEEN ORGANISM AND ENVIRONMENT

The action of all of the mechanisms which regulate the chemical relations of the organism is essentially to control the exchange of material which takes place between the organism and its surroundings. In its crudest form this mechanism acts simply by abolishing interchange between organism and environment when the characters of the latter become unsuitable. As these mechanisms develop in effectiveness, and, incidentally, in complexity, so do they increase in selectivity. They become able to control independently the exchange of a wide variety of substances with the outside world, and so to regulate the concentrations of these substances in contact with the living

matter that the organism may carry on its activities with a minimum of adventitious disturbance.

The fact that the living organisms of to-day have evolved from more primitive forms seems to involve the assumption that the mechanisms which have enabled living matter to survive have done so because of their ability to preserve at least some of its primitive characters. It will be interesting, therefore, to cite evidence which has been adduced in support of the hypothesis that living organisms tend to retain some of the properties which they may have possessed at very early stages of their evolution, no matter how complex they have eventually become.

Conjectures as to the series of reactions which may have led to the appearance of organic matter out of which the first living organisms were formed need not concern us. We are more concerned at the moment with the conditions of environment which may have existed when living forms were in the early stages of their evolution. It may be mentioned, however, that investigations such as those of Moore (1914) and of Baly (1927) and their coworkers have indicated the possibility of the synthesis of naturally occurring organic compounds from water, carbon dioxide, and inorganic salts under the influence of radiant energy and in the presence of inorganic catalysts.

No matter what the conditions may have been under which living matter first arose, they were obviously favorable to its appearance. Conversely, since the first living organism may be assumed to have been a direct product of its environment, there can be no doubt but that it was eminently well adapted to its surroundings. In the meantime, the conditions surrounding the living organism have undergone tremendous changes. As far as we know, none of the living organisms of the present day can be regarded as direct products of their environment.

When the composition of one of the higher forms of animal life is compared with that of its surroundings, the differences which are observed are much more obvious than the resemblances. Out of some 80 elements around it, the organism chooses 4 from which to build up about 95 parts out of every 100 of its substance. When, however, certain parts of an organism are compared with certain kinds of environment, a much closer correspondence can sometimes be seen, and there are indications that more intimate relations may once have prevailed between the two than can now be shown.

There must have been something fundamentally essential in the conditions under which life began. The enormous development of complexity which has taken place in some of the living organisms of the present day can be traced largely to the series of modifications which seems to have had for their object, the maintenance, in the

immediate vicinity of living matter, of conditions resembling those of its primitive state. From this point of view the whole story of evolution is one of adaptation to environment. It is a history of the mechanisms developed, of the subterfuges resorted to, of the changes undergone by living matter to maintain essential characters unchanged in a changing world.

There seems to be a general agreement among biologists that living forms originated in the sea. The chemical examination of organisms supports this view. All the reactions of living matter take place in aqueous solution. The ultimate units of structure, the cells, even of the most highly developed land forms, still live in a medium which bears certain striking resemblances to sea water.

We have no direct means of knowing what was the composition of the aqueous medium in which living matter first made its appearance. It must, however, have been a dilute salt solution, but of a composition differing materially from the sea water of the present time with respect both to the concentrations of and the proportions between the various ions present. The water which first condensed on the cooling surface of the earth would, in its course downwards to the lower levels, begin to leach out the soluble materials with which it came into contact. The more soluble materials would dissolve more readily than the less soluble. As this leaching action continued, the available supplies of the more soluble materials would diminish more rapidly than the available supplies of the less soluble substances. It may be assumed, then, that the earlier river waters, and the seas which they fed, were relatively richer in these more soluble materials than the waters of later periods.

During the period of their evolution in the waters of the seas, living organisms have thus been exposed to a medium of continuously, if slowly, altering composition. Does the study of the chemical composition of the living organism of the present afford any evidence that it has passed through these conditions? The individuals of the more highly evolved species during their ontogeny pass through a series of modifications of structure which summarize, as it were, the stages through which the present form of the species has been reached during the course of evolution. Macallum (1926) has shown that there is reason to believe that just as the complex organism acquired certain structures at definite stages of its evolution, so it has perpetuated certain of its chemical properties from remote phases of the history of its forerunners.

CHEMICAL AND MORPHOLOGICAL CHARACTERS

At present the ontogeny of the chemical characters of organisms is not known with anything like the detail which is available with

regard to their morphological development. A similar state of affairs exists with regard to our knowledge of the chemical phylogeny of living forms. The paleontologist has access in the sedimentary rocks to records of extinct species from which he can reconstruct at least some of their morphology. But as a rule the chemical characters of extinct organisms do not leave any direct record in the rocks. The information which we have as to the composition of extinct organisms is largely based on analogies drawn from our knowledge of the composition of existing structures homologous with those observed in fossil remains, or from the persistence of structures which were mainly composed of inorganic material.

Fortunately this rule is not entirely without exceptions. In one or two rare instances there is reason to believe that organic compounds present in long extinct organisms have been preserved from the remote past. It is a matter of pride to us to know that the latest of these rare discoveries has been made by a distinguished member of this society, our esteemed past president, Sir Edgeworth David. In the course of the examinations made in connection with his discovery of structures of living origin in pre-Cambrian strata, David (1928) observed that some of these structures consist of organic matter which is apparently the original chitin of which the skeletons of these animals (annelids) were largely composed.

Direct glimpses like this into what has been termed the paleochemistry of living things are of great importance. They give direct support to the otherwise very indirect evidence upon which is based our belief in the stability of some of the chemical characters of living organisms.

The paucity of our knowledge of the detailed composition of living things does not permit us to classify them in such small subdivisions as are made possible by our more detailed knowledge of their morphology. In this connection, however, the pioneering work of Smith and Baker (1920) must receive due mention. These investigators in their now classical researches followed out the relation between certain of the chemical constituents and the structure of a group of Australian plants.

Investigations of this kind, however, relate rather to the association which is to be found between highly specialized structures and compounds in living things. They bring out the changes which have taken place during the evolution of the chemical characters of living things rather than emphasize the relative permanence of some of the more primitive of these characters.

When we wish to consider the more fundamental chemical characters of the living organism, we must examine the less highly specialized tissues, and the wider divisions of morphological differentia-

tion. We must study the distribution of relatively simple inorganic compounds, rather than that of the highly complex organic substances. Only when comparisons are made on the basis of such broad distinctions of form as that between organisms having a closed circulatory system and those without it are correspondingly fundamental differences of chemical properties to be discerned.

THE PROPORTIONS OF CERTAIN CONSTITUENTS OF THE ORGANISM AND ITS ENVIRONMENT

There is no doubt that the unicellular organisms represent an earlier stage in the evolution of living things than do the metazoan or metaphytan forms. They probably flourished in the primordial oceans for long periods before multicellular organisms made their appearance. They must have been much more closely related to the medium from which they had been produced than the later forms. In particular, their inorganic constituents are likely to have corresponded fairly closely with those of the medium which bathed their cells. The differentiation between the medium and its product had not proceeded as far as it has reached in more complex forms of life.

It has been pointed out, however, that the inorganic composition of these primitive oceans must have been changing all the time. The effect of regulatory mechanisms in the cell would be to hinder, if not entirely to prevent, the changes from reaching the interior of the cell itself. By the time that living organisms had reached the state of complexity of the primitive multicellular structure, we may imagine them as groups of cells permeated by a solution which showed distinct differences in inorganic composition from that of the solution which bathed them. At first the surrounding medium would have free access to the cells of such a simple organism. But, as the complexity of the organism developed, access would become restricted to certain channels forming a primitive, open, circulatory system. The next stage in complexity would be the closure of these channels against the free ingress and egress of the surrounding medium, and the development of a closed circulatory system.

At this stage of evolution, the first barrier controlling the exchanges which take place between the cell and its environment would no longer be situated on the surface of the cell itself. Any changes which reached the liquid actually surrounding the cells would first be subject to the regulatory mechanisms in the outer surface of the organism and in the circulating fluid. The cell would be provided with an immediate environment to some extent under the control of the organism itself.

During all the period necessary for these developments, the change of composition of the surrounding medium would be still in progress. But once the action of a closed circulatory system became effective, the changes in composition of the medium bathing the cells would not proceed so rapidly. Although the composition of the external medium might continue to change, the changes would only reach the circulating fluid, the internal environment of the cells, in a modified form. The organism would tend to preserve the composition of the fluid with which it had been bathed while a closed circulatory system was being evolved.

Such an organism would be capable of very considerable independence of its external medium, an independence which would increase as its external regulatory mechanisms grew in perfection. Not until living organisms had reached this stage of complexity would they become able to emerge from the medium in which they had evolved, and their appearance as land forms of multicellular organisms become possible.

It is well known that the inorganic composition of the cells of various tissues of an organism differs materially from the inorganic composition of the circulatory fluid. According to the hypothesis outlined above, the inorganic constituents of the cells ought to correspond to those of sea water at an early stage in the evolution of living things. The composition of the circulating fluid ought, on the other hand, to correspond, with regard to its inorganic constituents, to the composition of sea water of a much later period.

Macallum (1926) has collected a good deal of evidence in developing this hypothesis. The most striking difference between the inorganic constituents present in the cells and those in the circulating fluids of one of the higher animals is the relative abundance of salts of potassium in the former and of salts of sodium in the latter. There is a remarkably close correspondence between the proportions of these two elements in the circulating fluid of the most highly organized living forms which have so far been developed and in the sea water of the present day. If the comparison could be made with the composition of the sea water during the period in which the vertebrates first appeared, the correspondence would perhaps be still closer, owing to the slightly greater proportion of potassium in the sea water of that period.

The difficulties in the way of forming an accurate estimate of the composition of sea water during the comparatively recent geological epoch in which vertebrates appeared are great enough. Much greater are the difficulties in the way of an attempt to form a similar estimate of the composition of the sea water of the remote age during which unicellular organisms were evolving. Even though no

attempt has been made to fix the proportion within narrow limits, it seems likely that the proportion of potassium to sodium must have been many times as great as it is at present. With respect to these elements, the composition of those primeval seas must have been considerably closer to that of the cell contents of the present day than to that of the circulating fluid.

Even when such diverse cellular tissues as human muscles and herring ova are examined, the difference between the relative proportions of sodium and potassium is not very marked. A general similarity of the proportions of these elements in cellular tissues is apparent. These considerations have been used to support the hypothesis that the living organism has retained with remarkable tenacity certain of the chemical characters imposed upon it at remote periods of its evolution.

THE CONCENTRATION OF THE ENVIRONMENT OF CELLS

So far only the proportions between certain elements in living tissue have been considered. It may now be asked whether the actual concentrations of chemical substances present also show any relation to those of the medium within which living organisms evolved during a considerable period of their history.

The most convenient single measure of the total concentration of materials dissolved in a liquid is the osmotic pressure. The data which have been collected by Botazzi (1908) show that osmotic pressures of the body fluids of the most highly developed groups of terrestrial living forms, vary only between remarkably narrow limits. When different forms of sea life are examined, however, a very different state of affairs is found. Even if the examination be restricted to vertebrate forms, wide ranges of osmotic pressure of the body fluids are met with. In the elasmobranchs, for example, the osmotic pressure of the body fluids is practically that of the sea water in which they live. In the teleosts, on the other hand, the osmotic pressure of the body fluids differs widely from that of the sea water and approaches the value found for mammalian fluids.

Dakin (1908) has shown that the differences observable among different species of fish are due to the fact that they possess adjusting mechanisms of different degrees of efficiency and not to the maintenance of specifically distinct levels of osmotic pressure. Specimens of plaice taken in a brackish portion of the North Sea gave values for the osmotic pressure of their blood 20 per cent lower than that of specimens taken where the osmotic pressure of the sea water was about 74 per cent higher. The osmotic pressure of the blood of cod, on the other hand, showed a variation of only about 3 per cent, while

the variations of osmotic pressure in the localities from which they were taken covered as wide a range as 64 per cent.

The same data which have been used to show that the proportions between some of the elements in the bodies of living organisms are perpetuations of the proportions to which these organisms were exposed at certain stages of their development, have been used to show that the osmotic pressure of the body fluids of the higher animals may also be a perpetuation of the conditions of an early stage of their development. The sea water at the time when these animals were developing closed circulations must have been much more dilute than it is to-day; its osmotic pressure has been assessed at a value only about one-third of what it is at present. Such a value would be very close to the osmotic pressure of the body fluids of the higher animals.

EXCHANGE OF MATERIAL BETWEEN ORGANISM AND ENVIRONMENT

The mechanism for the control of the proportions between certain of the constituents of the living organism must be of considerably more ancient origin than the mechanism for the control of the total concentrations of these constituents. Even the simplest unicellular organisms must be possessed to some extent of the former mechanism. The means for controlling the concentration of materials, as expressed by their osmotic pressure, has, on the other hand, only been developed in the most complex metazoa.

It has already been indicated that the action of the former mechanism is a result of the control which the barriers between the cell and its environment are able to exert over the passage of materials into and out of the interior of the cell. It will also be dependent to some extent upon what may for the moment be termed the "affinity" of the cell contents for certain of these materials.

Very little is yet known about the conditions governing the passage of different substances across the cell membrane into the body of the cell. The properties of the surface presented by the cells to their immediate environment must be the most important factors in the process. These properties are determined largely by the degree of dispersion of protein and phospholipide colloids of which the cell membrane largely consists. The proportions of the ions adsorbed to these colloids exercise an important influence on their condition. In particular, they affect the distribution of the dispersant medium (water) between their sol and gel phases, and so can vary the area of the portion of the surface through which water soluble substances would be able to pass.

The importance of maintaining the correct balance between the proportions of the ions in contact with living tissue was fully

recognized by Ringer (1884). In his classical series of papers he investigated in some detail the effect of variations of these proportions on the properties of living matter. These investigations have been the starting point of much of the later work. Hamburgher (1921), who made use of a rather highly specialized type of cell for his experiments, was the first to study directly this effect on the permeability of the cell wall. He was able to demonstrate clearly that variations of the proportions of the ions in the fluid to which these cells were exposed were able markedly to alter their permeability towards different materials.

Comparative studies have not so far been made to show how the power of the organism to regulate the relative proportions of the different elements, or more particularly ions, in its substance has developed during the course of evolution. A great deal of attention has been paid within recent years to the study of the proportions between the hydrogen and hydroxyl ions which are derived from the medium in which all the vital reactions take place. It seems, however, that the power of regulating the proportion between these ions must be of later development than the ability to preserve certain ratios between various other ions. Among the lower organisms considerable variation of the concentration of hydrogen ions may be survived by some forms. In the highest forms of life, however, the concentration of those ions is kept extraordinarily constant. It is allowed to vary between narrower limits even than the osmotic pressure. The proportions between certain inorganic substances in solutions, such as those in the neighborhood of and within living cells, determine what shall be the proportions between the ions of the solvent water. Indeed, even in the higher organisms, the occurrence of rapid variations in the proportions of these ions is prevented by the concentrations of certain other substances which are present. These are known as buffer substances. Among the inorganic salts which exercise this controlling action the more important are the sodium salts of carbonic and phosphoric acids.

The control of the permeability of the living cells must thus largely depend on the composition of the medium with which they are in contact, and on the presence of certain substances in the cells themselves.

The mechanism controlling the total concentration or osmotic pressure of the medium bathing the cells of an organism, on the other hand, must also be actuated by the composition of this medium, but in a manner different from that by which it influences the permeability of the tissues. It is true that the exchange of material between an organism with a closed circulatory system and its environment is limited to certain areas of its surface, for example, to the areas covered by the epithelium of the alimentary and respiratory tracts.

By these epithelia some selective action is, no doubt, exercised over the materials entering the organism. Their situation alone is such as to prevent access to them of any but selected parts of the environment. But as a characteristic feature of organisms possessing this mechanism is the freedom rather than the restriction of its exchanges with the outside world, the main regulatory mechanism must be sought elsewhere.

All organisms which have the power of regulating the osmotic pressure of their body fluids are provided with an excretory organ corresponding to a kidney. This mechanism exercises its control over the composition of the circulating fluid by eliminating from the organisms those constituents passing through it which are present in excess. It contributes to the independence of the organism of its environment, or, in other words, to its adaptation thereto, by placing another means at its disposal for keeping within suitable limits the immediate environment of its cells.

Even in those vetebrates in which the osmotic pressure of the body fluids is close to that of the surrounding medium there is a considerable degree of control exercised over the proportions of the various materials present. While the proportions between the various ions may be close to that of the sea water, their total concentration may be only a fraction of this. The remainder of the osmotic pressure in these cases is contributed by excretory products, principally urea, which are allowed to reach relatively high concentrations. This fact has been taken as evidence that the primary function of the kidney is not to excrete end-products of metabolism, but to adjust the composition of the immediate environment of the cells.

The possession of such a mechanism enables the organism to undertake more active measures to adapt itself to its environment and in some degree to adapt its environment to its needs. The environment of such an organism has already been modified before it gains access to any but specialized portions of the living substance. While, then, the cells of the organism are enabled to continue their existence under more or less primitive conditions, the organism as a whole is able to carry on its activities but little affected by the vicissitudes of a changing environment.

CONTROL OF ENVIRONMENT BY ORGANISM

(A) FOOD SUPPLY

In discussing the means taken by certain primitive organisms to adapt themselves to their surroundings, reference was made to the process of encystment and the performance of tropic movements. It was pointed out that in protecting the organism against unfavorable

conditions, these two classes of mechanism had at least one feature in common. They owe their effectiveness to the fact that barriers are placed between the organism and unfavorable conditions. In the first instance cited, the barrier is composed of the substance of the organism. The surface of contact between the organism and its environment is rather sharply defined. In the second instance, the barrier is composed of a part of the environment, which the organism places between itself and the unfavorable conditions. The change which takes place is not in the organism, but in the distribution of its environment about it. In neither instance, however, does the environment itself undergo any perceptible modification, nor does the organism itself appear to undergo further change.

As our definition of the term adaptation is the power to remain essentially unchanged in spite of external changes, it might be supposed that, as adaptive mechanisms increased in efficiency, they would bring about an ever sharper differentiation between the organism and its environment. An examination of the relevant data shows that what actually happens is just the reverse of this. Far from tending to isolate themselves more completely from their surroundings, the most perfectly adapted organisms are those in which the freest interchange is allowed with the environment.

Although the effect of each increase in the complexity of the mechanism of adaptation is to place additional barriers between the essential living unit, at the same time it extends further the range over which the organism is able to modify or, as it were, overlap its environment. Each adaptation, by increasing the intimacy of the relations between the organism as a whole and its external surroundings, protects the cell itself still more effectively from variations in the medium in which it lives.

One of the most important factors in the environment of an organism is the supply of available food materials which it contains. The ability favorably to control this supply must therefore be of great assistance to an organism to maintain itself in that uniform state which we have conceived as one of the principal aims of adaptive processes. This ability is possessed by man in an outstanding degree, but many organisms possess this power to a greater or less extent. It is seen more especially in the provision which they make for the nutrition of their young.

In oviparous animals and in many plants the young organism, when it leaves the body of its parent, is enclosed in a more or less impervious membrane which contains a supply of food material. By this means the young organism is able to pass through certain stages of its development in an environment which is entirely independent of outside fluctuations of food supply. In organisms of this kind,

direct association between the parent and its offspring ceases at a comparatively early stage of the development of the latter. This does not mean that the parent ceases to have any influence over the environment of its offspring as soon as the direct association between the two ceases. One need only refer to the elaborate precautions taken by birds to preserve a suitable environment about their young after hatching.

The direct association between parent and offspring persists in viviparous animals until a much later stage in the development of the latter. In these organisms, as in the former class, the environment of the young during the period of gestation is furnished by the circulating fluid of the body of its parent. The variations of this fluid are kept within certain limits by the regulatory mechanisms of the parent. The young organism is thus provided with a medium of constant properties while its own regulatory mechanisms are developing. In some viviparous animals the association between parent and offspring ceases almost completely at birth, and the young organism, having been provided with its own adjusting mechanisms, as efficient as those of its parent, is left to adapt itself to its new surroundings.

Like most of their adaptive mechanisms, the devices of mammals for the care of their young are more complex and effective than those of other forms of life. In addition to the protective measures to which allusion has been made, the mammals provide for their offspring a special food, milk, during part of their extra-uterine life. The period for which this provision is made varies widely among different species. In man it extends, under natural conditions, over the greater part of a year, in some races much longer.

This mechanism for the adaptation of one factor of the environment to the needs of the organism, represents one of the last stages in adaptation by modifications of bodily structure and function. It is interesting to observe how closely, in this latest adaptive mechanism, certain properties of the environment are adjusted to the needs of the organism.

It should be remarked at the outset, however, that one of the most striking properties of milk has probably no significance in relation to its use as a food by the young organism. This is the fact that the osmotic pressure of milk has a value very close to that of the body fluids of the animal by which it is consumed. Milk probably owes this property to the manner of its secretion from the body fluids of the maternal organism. Before the milk is absorbed by the young animal, certain of its constituents must undergo a process of digestion or hydrolysis. The sum of the osmotic pressures of the products of digestion is considerably greater than that of the original

milk, so that the osmotic pressure of the solution actually absorbed differs materially from that of the body fluids of the young animal.

When the composition of milk is examined, it is found that although the proportions of the various constituents show considerable variations among different animals, and even among individuals of the same species (Wardlaw, 1915, 1917, 1926), the same constituents are present in each. The concentration of each constituent appears to be adapted to the needs of each species. It will be remembered that in considering the relation of the most primitive living organisms to their environment, some of the evidence was mentioned which seemed to point to a close relation between the proportions of certain elements of inorganic compounds present in the surrounding medium, and the proportions of these elements in the body of the organism itself.

A comparison between the proportions of the various elements in the inorganic, or more strictly speaking, the incombustible portions of milk and the proportions of the same elements in the bodies of the young organisms which consume the milk, also shows a remarkable correspondence. These proportions are not those of the circulating fluids of the animals. An explanation of this correspondence is not to be sought, therefore, like that between the osmotic pressure of milk and body fluids, in an incidental transference of certain properties from the circulating fluid of the maternal organism to its offspring. The correspondence seems to be due to a definite adaptation of this part of the environment to the needs of the young animal.

A similar correspondence between those organic constituents of the milk, which are used as building materials, and the composition of the young organism has not been found. This is partly, no doubt, because it would be a matter of very great difficulty to estimate separately the various units into which the proteins of milk are broken up in the course of digestion. But may it not be due, in part, to that more primitive and intimate relation between the inorganic constituents of a living organism and its nutrient medium to which the evidence discussed earlier seems to point? The most primitive living things must have had practically no relation to organic compounds in their inorganic environment. The organic compounds of their own cells they synthesized themselves. The relation between the organic constituents of the organism and those of its environment can only have become of importance at a much later stage in the development of living things, and is likely to be less intimate than that with the inorganic constituents. If this be so, it gives further support to the supposition that certain of the fundamental properties of living matter of to-day are perpetuations of conditions which existed when life was at its beginning.

It must not be thought, however, that numerous adaptations of the organic portions of milk to the needs of the young animal can not be shown. The organic constituents of milk may be divided into those which can only be used as fuel and those which furnish material for the construction of the body of the young animal. If we compare the milks of animals whose young grow at different rates, for example, we find that there is a definite relation between the concentration of the organic building materials and the rate of growth, the concentrations being greater in the milk of the more rapidly growing animals. A similar relation, incidentally, is to be seen between the rate of growth and the total concentration of the inorganic constituents.

Even the constituents of the milk, which serve only as fuels, although they play no part in the contribution of material for building up the body of the young animal, show adaptations to the various needs, not merely of different species, but even of different individuals.

The young of warm-blooded animals living in cold climates are, for example, exposed to greater losses of heat than those of animals living in warmer regions. We find a correspondingly higher concentration of the fuel, fat, in the milk of the animals indigenous to cold regions. Again, other things being equal, small animals tend to consume relatively greater quantities of energy per day than larger animals. The milk of small animals is, in general, richer in fat than the milk of larger animals. This relation can not only be seen among different species of mammals varying widely in size, but even in individuals of the same species. The small Jersey cow, for example, yields a milk richer in fat than larger breeds.

The range of variation of size among human individuals is much smaller. The correspondences between the composition of the milk and the needs of the human infant are, therefore, much less obvious. They require a closer scrutiny for their discovery. But it may be shown, by suitable methods, that there is a definite correlation between relatively slight variations of the physical characters of healthy infants and the composition of the milk with which they are supplied by their mothers (unpublished observations). This is surely a striking example of the length to which the adaptation of the immediate environment to the needs of the organism is carried by the most highly organized of all animals.

(B) EXCHANGES OF ENERGY

None of the devices to which the living organism resorts for the control of the composition of its immediate environment can exert its full effectiveness if the temperature of this environment is

allowed to vary unrestricted. Still less, under these circumstances, can the organism attain that freedom from external variation of the rate of its activities which seems to be one of the principal objects of adaptive mechanisms. The rates of chemical reactions vary rapidly with the temperature at which they take place. The effect of these variations upon the activities of organisms without a temperature-regulating mechanism is so striking and so familiar as to require no further reference.

The effect of variation of temperature on the composition of living tissues and of their immediate environment is not so obvious, but is none the less important. Variations of temperature alter the equilibrium constants of chemical reactions. In this way they alter the proportions between the reacting materials which will exist under given conditions. For example, the proportions between the ions in the circulating fluids and cells will not be the same at different temperatures. We have seen the permeability of the living cell is largely controlled by the proportions of the ions present in its immediate vicinity. As it is this permeability which determines many of the fundamental properties of living matter, these properties must be modified by changes of temperature, quite apart from any changes in the rate of the vital activities which they may bring about.

The temperature-regulating mechanisms of all the warm-blooded animals are by no means equally effective. In the higher mammals this mechanism continues to function as long as the external conditions of temperature remain within limits compatible with the life of the animal. In other species, however, the mechanism goes out of action if the temperature of the surroundings falls below certain levels which the animal can still survive. At these lower temperatures the animals behave like cold-blooded animals and have body temperatures close to those of their external environment. This is the phenomenon of hibernation. The ease with which this mechanism is thrown out of action by a fall of temperature differs among different species. It is interesting to observe that in *Echidna*, which, on morphological grounds, is regarded as the most primitive of mammals, the action of the heat-regulating mechanism is peculiarly susceptible to disturbance. It ceases to function at external temperatures several degrees higher than those at which an effect is to be seen in other hibernating animals. (Wardlaw, 1915, 1921.)

It is well known also that the effectiveness of the mechanism for the regulation of body temperature of warm-blooded animals is much less efficient in the immature individuals than in the adults. Even in normal infants, for example, the fluctuations of body temperatures are much greater than those of adults, while in premature infants this mechanism is so ineffective that survival is often impossible

without the aid of artificial means for keeping the body temperature within suitable limits.

The advantage of a mechanism to free the organism from the effects of still another variable of its environment need not be further stressed. In analogy with the possible connection between certain of the chemical characters of the living organism and the composition of the medium in which it lived at different stages of its development, it might be suggested that the constant temperature of warm-blooded animals is also a perpetuation of conditions which prevailed while this mechanism was being developed. But even such scanty data as those on which the previously mentioned suppositions have been based are in this case lacking.

The living organism is constantly liberating energy, part of which appears as heat. To preserve a constant body temperature it must, therefore, maintain a balance between the rates at which heat is lost and produced. This balance can be maintained by the exercise of a control over one or both of these rates. As one of the principal objects of adaptive mechanisms seems to be to protect the organism against adventitious variations of the rate of its activities, it might be expected that the control of temperature would be effected by regulation of the rate of heat loss rather than by variation of the rate of heat production. This expectation has, to a considerable extent, been realized in the warm-blooded animals which have been studied from this point of view in sufficient detail, the dog, and man.

It has been found that when these animals are examined under comparable states of activity, the rate at which they produce heat is affected only to a minor extent, even by considerable variations of the temperature of their surroundings. Not only is the organism of these animals able to restrict the loss of heat from their bodies when the external temperature falls, but they are also able to continue to lose heat to their surroundings, even when the external temperature is above that of their bodies. There are, of course, limits beyond which this mechanism becomes ineffective. If the external temperature rises too high, or if the conditions of humidity are such as to restrict unduly the loss of heat by evaporation, then heat production will exceed heat loss, and the body temperature will rise. The organism is incapable of decreasing its production of heat below a certain value even under these circumstances.

If the external temperature falls to a low enough level, the mechanism for regulating body temperature by controlling the heat loss also becomes ineffective. The body under these circumstances, however, does not lose its power of maintaining a constant temperature, because it is able to increase its heat production until its heat loss is again balanced. The object of the constant body temperature, the

maintenance of a constant rate of metabolic activity under given conditions, is certainly nullified to some extent by this adjustment. The organism is outside of the range of perfect adaptation to the temperature of its environment. But, on the other hand, such conditions, even when the external temperature is extremely low, can be survived indefinitely without apparent detriment to the organism. On the whole, therefore, the organism can adapt itself to temperatures below that of its body better than it can to higher temperatures.

RATE OF ADAPTIVE CHANGE

As the range and the scope of the mechanisms by which the organism is able to modify its environment increase, the necessity for adaptive changes on the part of the organism itself must correspondingly decrease. Thus we are led back to our original postulate that the more effective any adaptive mechanism is, the better does it enable the living organism to persist unchanged in a changing environment. We should, therefore, expect evolutionary changes of structure and function to become progressively slower as we pass to more and more complex organisms, and the mechanisms which were at first developed to preserve the primitive characters of the cell itself, eventually to become so effective as to be able to preserve the characters of the whole organism.

The organism which possesses, in an outstanding degree, the ability to modify its environment is, of course, man. He controls his food supply by the hunting and rearing of food animals, by the gathering and sowing of edible plants. He modifies certain of his external conditions by the wearing of clothes and the erection and use of houses. He adds to the effectiveness of his hands by the use of tools. He increases the speed and the range of his movements by traveling in vehicles. By means of various instruments he adds to the acuity of his sense organs. All these external aids to his natural powers may be classed as tools. It is his ability to devise tools which has extended his ability to adapt his environment to his needs so immeasurably beyond the similar power of any other animal.

One of the most striking features of this type of adaptive mechanism is the extraordinary rapidity with which it has been developed, as compared with the evolutionary modifications of bodily structure.

The conjectures which have been made as to the period which has elapsed since the appearance of living forms runs into hundreds of millions of years. The period for which records can be obtained of the existence of man is measured, on the other hand, by hundreds of thousands of years. However vague those estimates may be, there seems to be little doubt that the enormous development of complexity which some living forms have undergone has occurred within a small

fraction of the time during which living organisms have been in existence. The development of the power of man to modify his surroundings as a result of the development of his mental faculties is a still more rapid and recent growth and is to be measured in centuries. Indeed, it may be claimed that man has expanded his powers in this direction more during the last century than during the whole of his previous history.

We have in man, then, the most perfect adaptation to environment shown by any form of life. So great is his power of modifying his surroundings, and so rapidly is this power increasing, that it would seem that further adaptation of his physical structures has become unnecessary. It has even been suggested that his increasing use of artificial mechanisms may bring about a degeneration of some of his bodily powers, and that any further evolutionary development in man may be restricted to the growth of his mental faculties. The past history of the evolutionary adaptation of living organisms to their environment would, however, lead us to expect that any changes which may take place in the organism of man will not be such as would adversely affect the conditions of life of the essential units of his structure. In so far as the changes which have taken place in his habits of life are really adaptations to his environment, we may expect that their effect will be to establish more securely the primitive conditions of his cells.

SUMMARY

A characteristic feature of living organisms is the possession of mechanisms which protect them against the effects of changes of their environment.

These mechanisms in the earlier forms exert their action by restricting the interchange which they allow between the organism and its surroundings. As they develop in efficiency, they become more selective in action, and are able to preserve the essential characters of the organism while allowing a free interchange with its environment. They have preserved, even in the higher organisms, some of the conditions of cell life which probably existed at very early stages of their evolution.

When sufficiently broad distinctions of form are considered they are found to possess equally distinct chemical features, for example, in the proportions of some of the elements which they contain.

As the complexity of organisms has increased, they have rendered themselves more independent of their external environment by providing their cells with an immediate environment of their own. By this means external changes are only allowed to reach the cells in a modified form. The possession of this internal environment enables

the organism to obtain the advantages of a freer interchange with its surroundings without endangering the stability of its essential living matter.

The evolutionary development of the adaptive mechanisms of the organism has continually extended the range and scope of its control over its environment. Examples of the most highly specialized forms of this control are the maintenance of a constant body temperature by homoiothermal animals, and the provision of a special food supply for their young by mammals.

As the effectiveness of the mechanisms for the adaptation of the environment to its needs has increased, the need for further adaptive modification of the organism itself has correspondingly diminished.

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THE UTILIZATION OF AQUATIC PLANTS AS AIDS IN MOSQUITO CONTROL[1]

By Prof. Robert Matheson

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[With 7 plates]

Our knowledge of mosquitoes has been acquired in very recent years. Previous to 1898, the year in which Sir Ronald Ross announced his epochal discovery that "dappled-winged" mosquitoes are the intermediate hosts of the malarial parasites, scarcely anything was known of these fiercely biting foes of man and animals. Their blood-thirstiness was well known, for in many portions of the earth man was unable to withstand their attacks and some of our fairest regions had to be abandoned to these tiny victors. Even to-day man is rather helpless before them. The writings of explorers, travelers, etc., often contain accounts that give us a picture of the fierceness and terribleness of a mass mosquito attack. Since 1898 we have acquired an immense amount of detailed information about the disease relationships, habits, life histories, biology, etc., of mosquitoes. To indicate briefly some of these advances seems worth while before attempting to outline the importance that plants may play in solving the problem of mosquito control.

Previous to 1896 the life history of practically only a single species, the common house mosquito (*Culex pipiens*), was known. In 1900 Dr. L. O. Howard published the first account of the life history of an American anopheline. As *Anopheles* species are the vectors, and the only known vectors, of malaria, the study of these mosquitoes has been very intensive, especially since the World War. Malaria is probably one of the most widespread and most serious of all human diseases. Though quinine and its various derivatives are used extensively in alleviating the attacks of malaria, they are not specific cures, and the only effective method is the control of the anopheline carriers. In 1900 Dr. Walter Reed and his associates announced the

[1] Reprinted by permission from the American Naturalist, vol. 64, January–February, 1930.

discovery that yellow fever is conveyed from man to man by a mosquito, the so-called tiger mosquito (*Aedes aegypti* or *Aedes argenteus* or *Stegomyia fasciata*). This discovery greatly increased the activities of the students of mosquito biology. Yellow fever is endemic to the Americas, but was established in west Africa sometime before 1900.[2] Recent outbreaks in Africa have aroused world-wide interest. Until 1928 it was confidently stated that only the tiger mosquito was the vector of yellow fever. Bauer (1928) has demonstrated that at least three other species may be vectors in west Africa.[3] Long before this (1879) Sir Patrick Manson had shown that a round worm (*Filaria bancrofti*) of man had a mosquito as its host for part of its life cycle. It was not, however, till 1900 that the method of transfer of this parasite was finally established. The variety of diseased conditions produced in man by this parasite is even yet not well known. This parasite is widespread throughout the tropical and subtropical regions of the world.

Dengue, a febrile disease of man which often appears in epidemic form in the tropical and subtropical regions, was shown in 1903–4 to be transmitted by a mosquito (*Culex fatigans*). Recent work seems to prove conclusively that *Aedes argenteus*, the yellow-fever mosquito, and *Aedes albopictus* are the vectors. In addition to these diseases of man, several animal diseases are transmitted by mosquitoes.

The knowledge that mosquitoes are the vectors, and probably the only vectors, of these serious diseases of man has led to a world-wide intensive study of mosquito biology. In 1900 some 242 species were known from the world. To-day probably over 3,000 species are recorded. All known species of mosquitoes pass their larval stages in water. They are known to breed in a great variety of aquatic environment—in ponds, slow-flowing streams, swamps, salt marshes, pools formed by melting snows, all sorts of artificial water containers, foul and clear water, reservoirs, rice fields, irrigation ditches, water in tree holes, in the water contained by the leaves of epiphytic bromeliads, in the water in the leaves of pitcher plants, etc. However, from all these studies we are beginning to learn what are the aquatic conditions essential for the breeding of each species of mosquito. This has led to more intensive studies of certain species to determine why certain types of aquatic environment are selected, and others, apparently identical as far as we can judge, are avoided. It was early recognized that not all types of water were selected by mosquitoes, but it was not till the past few years that attempts were made

[2] It is now believed that yellow fever had its original home in West Africa and was introduced into the Americas by the early navigators and explorers.

[3] At the present time (1932) at least 12 different species of mosquitoes are known as transmitters of yellow fever (7 species for Africa, 2 for South America, 2 for the Far East, and 1, *Aedes aegypti*, of wide distribution).

to solve the riddle of this selective breeding. It may be admitted at once that this riddle is far from solved, though the chemical and physical properties and the fauna and flora of breeding places have been rather intensively studied by various workers.

The early investigators, noting the absence of mosquito breeding in certain ponds, pools, etc., tried to offer explanations for such conditions. These explanations ran the gauntlet of a wide variety of surmises, usually observing that the water was unsuitable, that there was lack of the necessary food (though the food requirements were not then known and are not even at the present time), or that the excessive plant growth covered the surface of the water so as to prevent the larvae from obtaining air, or that filamentous algae were abundant in which the larvae became entangled and died or that numerous natural enemies, as predacious fishes, insects, etc., were present.

That aquatic plants may act as destroyers of living organisms was observed quite early. Mrs. Treat (1875) noted that the bladders of a *Utricularia* sp. contained many organisms, including insect larvae, and she tried to solve the mystery as to how these animals were caught and if the plant used them as food. Darwin (1875) in his "Insectivorous Plants" gives a much more detailed account but failed to solve the mystery of how the organisms were trapped. Brocher (1911) fully solved the process, which was later confirmed by Hegner (1926). Different workers in various parts of the world have called attention to this group of carnivorous plants and their possible utilization as agents in mosquito control.

PREDACIOUS PLANTS

The commonest species is probably *Utricularia vulgaris* (pl. 1, fig. 1). It often occurs in great abundance floating directly below the surface of the water. The numerous small bladders and finely divided leaves distinguish it quite easily. The bladders are most interesting structures and have been fully described by Brocher and Hegner. These bladders, when "set" for the capture of prey, have their side walls rigidly compressed; organisms then enter the outer vestibule and by their movements stimulate the closing valve which suddenly opens, the side walls expand and the inrushing water carries the entrapped animal within. The valve then closes and the organism is firmly held. Within the bladders the animals are gradually digested and furnish food for the growth of the plants. The enormous amount of food taken by these plants may be illustrated by some of Hegner's observations. He found that the bladders on parts of a plant 220 cm (nearly 7 feet) long contained approximately 150,000 small crustaceans, besides other organisms. From the standpoint of mosquito control the question may be asked, do these

bladders capture mosquito larvae and how many? Franca (1922) observed them capture numerous larvae of *Theobaldia longiareolata* and *Anopheles bifurcatus*; Brumpt (1925) records the capture of the larvae of *Anopheles maculipennis* and *Culex apicalis*. During the summer of 1929, I carried on a few experiments with this plant to determine the rate of destruction and the size of larvae they could capture. Plate 2, Figure 2, shows a small branch containing 10 active bladders. In five of these may be seen mosquito larvae in various stages of digestion. I have had them capture the smallest larvae and readily destroy the largest larvae I could obtain. Two preliminary experiments were conducted to determine the effectiveness of this plant in small aquaria. Two small branches were placed in a battery jar with 50 young larvae of *Culex territans*. On the following day only two free larvae could be found; the bladders contained the others. During the next four days 375 larvae were added and practically all were captured, though toward the end of the experiment nearly all the bladders had dropped from the branches. How long a single bladder may live and how often it can capture such large prey as mosquito larvae, are not known. In another similar experiment, 225 larvae were added and practically all these were captured before the bladders began falling from the plant.

In order to test the size of animals captured, large larvae of *Brachydeutera argentata* Walk. (Ephydridae, Diptera) were added to an aquarium with Utricularia. The results are shown in Plate 1, Figure 2. In cultures of Utricularia large numbers of these larvae were readily captured. Though only a small portion of the larva is first taken into the bladder, our observations show that eventually the entire larvae is absorbed. How this is done is not easily explained.

Though the captured food of the Utricularia would appear to be mainly small organisms belonging to the Crustacea, Protozoa, etc., yet it would seem that this group of plants deserves more consideration as a possible agent in mosquito control. The bladderworts are very graceful plants, grow luxuriantly where they occur and ought to make an added attraction in fishponds, small lakes, private pools, etc. Unfortunately we know very little about their biology or methods of their culture.

SURFACE-COVERING PLANTS

Another group of plants that has attracted considerable attention among students of the mosquitoes comprises the surface-covering aquatic plants. These plants are often packed so closely together

that the entire surface is covered, causing the larvae to die from suffocation, or the plants in some way inhibit the female mosquitoes from laying their eggs in such situations. Smith (1910) investigated the reported effect of a species of *Azolla* growing on the water in the canals of Holland. Here he found it in certain regions, the peat and turf areas, growing in such profusion as to cover the canals completely and prevent mosquito breeding. This plant seems to have restricted breeding areas, and though introduced into America its growth was not very successful. Conflicting reports as to its value have since been published, but as far as I know no experimental work has been undertaken to test its reported value. MacGregor (1920) thinks that *Azallo filiculoides* is a deterrent to anopheline breeding. He found no larvae or egg deposition in experimental tanks covered by this plant, whereas oviposition and breeding took place in near-by tanks containing other kinds of aquatic plants. Eugling (1921) states that the planting of *Azolla* in Albania seems to favor the breeding of anophelines. Mühlens (1924, 1925) reports that in parts of Argentina he found no mosquito larvae in pools and lagoons covered with *Azolla* sp. and *Azolla filiculoides*, whereas in near-by pools where these plants were absent mosquitoes bred in abundance.

Various species of the *Lemnaceae* (duckweeds) have been reported as effective water coverings (pl. 3). In New Jersey, Johnson (1902) found that no mosquito breeding took place where the *Lemna* formed a complete mantle but where open spaces occurred *Culex* and *Anopheles* bred in small numbers. Furthermore, *Lemna*-covered ponds harbor numerous predacious insects which attack mosquito larvae. Howard, Dyar, and Knab (1913) state that one of the most abundant breeding grounds of *Culex salinarius* was a large marsh completely covered by *Lemna*. Bentley (1910) found that species of *Lemna* were of no value but that a related plant, *Wollfia arhiza*, was quite effective in the tanks in and around Bombay. In Sardinia, Fermi (1917) recommends the planting of *Lemna palustris* where oiling can not be employed. In Corsica, Regnault (1919) reports that *Lemna* was successfully grown and prevented mosquito breeding. Whenever the *Lemna* disappeared breeding took place. In Russia, Vasilev (1925) found that wherever *Lemna minor* and *Lemna polyrrhiza* covered the surface no mosquito larvae could be found. Other workers present very conflicting reports, but the evidence of general observations would seem to indicate that the various species of the *Lemnacae* may prove of value in reducing the abundance of mosquitoes. Plate 3 shows an enlarged (magnified about seven times) view of *Wollfia punctata* and *Lemna minor* cov-

ering the surface of water. In ponds about Ithaca where these species grow in abundance few larvae are present. However, our knowledge of the growth or culture of these plants is very limited. A pond (pl. 4, fig. 2) which for years past had a compact covering of *Lemna minor* suddenly in 1929 became densely coated with *Wollfia punctata*, the *Lemna* occurring only in small patches.

From all these conflicting observations one fact stands out clearly—that the study of the growth, culture, distribution, and usefulness of surface-loving plants deserves the especial attention of botanists and those engaged in the problems of mosquito control. This may be further emphasized by the report of Williamson (1928) that in Malaya the blue-green alga, *Microcystis*, forms a dense scum in foul waters, and this accounts for the absence of anopheline larvae.

NONSURFACE-LOVING AQUATIC PLANTS

Though predacious and surface-loving aquatic plants deserve more study, those graceful plants belonging to the *Characeae* aroused the attention of mosquito workers when Cabellero (1919) announced that *Chara foetida* had a marked effect in inhibiting the development of mosquito larvae. This and his later studies awakened a renewed interest in the study of aquatic vegetation in relation to mosquito breeding. These studies have centered largely about the *Characeae*, and numerous conflicting reports have been published in recent years. The various species of *Characeae* (pl. 7, fig. 1) are beautiful and graceful plants often growing with remarkable vigor and forming a most pleasing bottom covering for otherwise unsightly ponds. The species of *Characeae* are very difficult to identify, and many workers seem to be of the opinion that certain species do inhibit larval growth, while others have no effect. What are these species? This question has not yet been answered, for the experimental work with the various species has been very limited. Most of the published results deal with general field observations, and there is no indication by these various authors as to the exact conditions under which the observations were made. Was the *Chara* sp. growing vigorously? Were the ponds fouled with wastes? Were they temporary or permanent ponds? Were they spring fed, from overflows, surface water, or from other sources? In other words, an exact analysis of the aquatic environment is seldom given. In general, such workers as Allaud (1922) in Morocco, Langeron (1921) in Tunis, Maynar (1923) and Pardo (1923) in Spain, Federici (1928) in Italy, and Buhot (1927) in Australia have presented brief experimental data that seem to confirm the findings of Cabellero. On the other hand, the work of MacGregor (1924) in England,

Barber (1924) in the United States, Fisher (1924) in Panama, Buxton (1924) in Palestine, Swellengrebel (1925) in Holland, Reyne (1924) in Surinam, Vasilev (1925) and Tarnogradski (1925) in Russia, and Hamlyn-Harris (1928; 1929) in Australia would indicate that the *Characeae* have little, if any, effect on mosquito breeding. Blow (1924) reports little mosquito breeding in Madagascar where species of *Chara* abound, but in 1927 he states that the *Charophyta* (*Characeae*) possess no larvicidal qualities. Hacker (1922) reports doubtful results in the Federated Malay States. Such conflicting results would indicate that we know very little of the underlying factors that induce or prevent mosquito breeding. Every worker is fully aware that certain types of aquatic situations induce mosquito breeding, whereas other or even almost identical situations do not bring about breeding. In other words, we have what may be called the selective breeding habits of each species. What are the factors that control or govern such selective breeding habits?

Early in 1923 I was impressed by such conditions in central New York and began a certain line of investigation in an attempt to answer some of these questions. The discovery of a permanent spring-fed pool (pl. 5, fig. 1) richly carpeted with a growth of *Chara fragilis*[4] enabled me to plan a line of work which might promise some results. In this pool, and similar ones since discovered, no mosquito breeding took place. It seemed ideal as a mosquito habitation. Farmhouses were located near by, and cattle grazed in large numbers in the surrounding pastures, so that the adults had a ready source of blood. Why, then, do mosquitoes fail to breed here? A few preliminary experiments made in 1925 seemed to indicate that the carpeting of *Chara fragilis* might be the inhibiting factor. Nothing further could be done till the spring of 1927. At that time I attempted to obtain answers to the following questions: (1) Does this species of *Chara* have an inhibiting effect on larval development? (2) Will mosquitoes oviposit readily on *Chara*-filled pools, and if they do what becomes of the larvae that hatch out? (3) If *Chara* has an inhibiting effect on the development of the larvae what is the causal agent? (4) Or, if the presence of *Chara* inhibits oviposition what are the factor or factors involved? (5) What is the food of mosquito larvae?

To answer the first question a long serious of experiments was conducted in aquaria in our greenhouse (pl. 4, fig. 1). The aquaria were stocked with *Chara fragilis*, and the larvae of various species of mosquitoes were added from time to time. Water from a near-by

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[4] This species is now determined as *Chara vulgaris* Linn.

stream was used both in the *Chara* aquaria and in the controls. In the controls the larvae seemed to develop normally so whatever food was necessary was present in the water added to the *Chara* aquaria. The results of these experiments are briefly summarized in Table 1.[5]

TABLE 1.—*Results of Chara experiments*

Species	Number of larvae	Stages of larvae	Adults emerged	Number died	Time required
Aedes vexans	2,500	Second to fourth	115	2,385	2 to 14 days.
Culex pipiens	4,500	do	379	4,021	Do.
Culex territans	1,100	Various	108	1,092	2 to 15 days.
Anopheles punctipennis	146	do	8	138	3 to 25 days.
Aedes canadensis	800	Young	223	577	4 to 10 days.
Aedes stimulans	1,250	Various	64	1,186	6 to 17 days.
Total	10,296		897	9,939	

The table is self-explanatory. Not a large variety of species was tested in the experiments, but out of 10,296 larvae there was an emergence of only 897 adults. In the controls our emergence records show that nearly all the larvae produced adults. What, then, is the factor or factors that prevented these larvae from completing their development? I thought at first that the plant might produce some lethal substance, judging from the rapid death rate of the larvae. This, however, seemed to be ruled out, as a great abundance of Cyclops, Daphnia, and other small Crustacea, as well as numerous phytoplankton, thrived in the experimental aquaria. A factor experimented with was the pH values (acidity versus alkalinity). The experimental aquaria and our *Chara* pounds showed a wide daily cycle of pH values, usually running from a pH of 7.6 to nearly 9.4 each day. The water was always alkaline and following MacGregor (1921) and Senior-White (1926) I thought the changing alkalinity might account for the high death rate. Further experiments confirmed the results of other workers that pH values have probably little to do with inhibiting larval development. The next factor was the study of the food requirements of the larvae. Could it be possible that *Chara* ponds and our *Chara* aquaria did not possess sufficient food for the development of the larvae?

An intensive search of the literature showed that the main larval food consists of the zooplankton and phytoplankton organisms found in the water. These are swept in by the action of the larval mouth brushes, and everything that can be swallowed is taken in indiscriminately. Along with these substances is swept in a considerable amount of water. Fortunately I had begun an intensive study of the plankton of a typical mosquito-breeding pool and the spring-fed

[5] Full details may be found in the Amer. Journ. Hygiene, vol. 8, pp. 279–292, 1928.

Chara pond. This investigation [6] soon showed a greater variety and a much higher density of plankton organisms in our *Chara* pond and aquaria than that found in a typical mosquito-breeding pool. If plankton organisms are the food of mosquito larvae, here then was an abundant food supply and yet they died amidst plenty. However, I have never fully believed that plankton organisms constitute the entire larval food but that the larvae probably obtain most of their food from substances in solution in the water and from decaying organic wastes. My assistant was in the midst of testing this theory, and his preliminary results indicated that my thesis held true for the species with which he was experimenting.[7] If plankton does not constitute the main food of mosquito larvae but rather substances in solution and organic wastes, then the question is does the *Chara* remove these substances in solution so rapidly as to starve the larvae? Decaying organic matter is largely absent in *Chara* ponds, as one of their marked characteristics is the crystalline clarity of the water. I could find no way to test all these suppositions experimentally.

There was still another factor which always excited my curiosity, more especially since the publication of Cleveland's work in defaunating the intestinal tract of termites with oxygen. As *Chara* gives off during the day an immense number of tiny bubbles of oxygen I felt fully convinced that the larvae must sweep hundreds of them into their intestines. What effect could the presence of oxygen have on the digestive processes of the larvae? To test this I devised a rather simple apparatus. Pure oxygen was passed, under pressure, through Berkefeld filters N and W and entered the water in bubbles almost as tiny as those given off by the *Chara*. Plate 1, Figure 1 shows the apparatus in operation. Two cylinders are being treated with oxygen while two others serve as controls. The same water and food were supplied to all the jars. This experiment was conducted for a considerable time and a brief summary is presented in Table 2.

TABLE 2.—*Tests with oxygen*

Species	Number of larvae	Number died	Number of adults	Time exposed	Controls
Culex sp	50	50	0	3 days	Adults emerged 2 days later.
Do	50	50	0	7 days	Adults emerged as experiment ended.
Do	50	50	0	3 days	Adults emerged a few days later.
Do	50	50	0	4 days	Do.
Anopheles punctipennis	20	?	A few.	9 days	Adults all emerged in controls.

[6] The results were published in detail in the American Journal of Hygiene, vol. 11, pp. 174–188, 1930.

[7] Full account by Hinman, Amer. Journ. Hygiene, vol. 12, pp. 238–270, 1930.

These experiments, and many others which were tried, indicate that the oxygen present in the water in small bubbles may be ingested by the larvae and may bring about a high death-rate. The larvae in the oxygen-treated cylinders appeared irritable, and though their intestines were filled with apparently normal food yet their growth was slow and they gradually dropped to the bottom and died. There was great difficulty in preventing the oxygen bubbles from accumulating at the surface. Whether or not larvae could break through the surface film with their air-tubes remains unsolved. This may prove the real reason for the death of the larvae. However, the presence of the oxygen in the intestines (not proved, except by inference) may interfere with the digestive functions and bring about the death of the larvae. It may be recalled that Cleveland (1925) brought about the death of termites by defaunating their intestinal tracts by means of oxygen. In this case the oxygen killed the commensals (Protozoa) which converted the eaten wood into substances capable of being digested by the termites. What oxygen may do in the intestinal tracts of mosquito larvae remains to be solved.

In addition to the aquaria experiments with *Chara* a long series of tests was conducted with wooden tubs sunk in the ground (pl. 5, fig. 1), with wooden tanks divided into compartments (pl. 6, fig. A) so that there would be *Chara* growths separated from the ordinary water by screens, and also to provide a method of testing *Chara* in still as compared with running water. The results of these experiments [8] were uniformly successful and gave additional evidence that *Chara fragilis* in some way prevented the development of the larvae.

The second problem, do females normally oviposit in pools containing vigorous growths of *Chara*, was also tested experimentally. A series of aquaria filled with a growth of *Chara fragilis* was set up in our greenhouse (pl. 4, fig. 1). An abundant supply of the adults of two *Culex* species (*C. pipiens* and *C. territans*), *Anopheles punctipennis*, and *Aedes aegypti* (the yellow fever mosquito) was at all times present in and about our experimental quarters. The results of these experiments are shown in Table 3.

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[8] A full account of these experiments may be found in the Amer. Journ. Trop. Med., vol. 9, pp. 249–266, 1922.

TABLE 3.—*Aquaria experiments with Chara fragilis to test egg deposition*

Experiment No.	Time set up	Maximum pH	Condition of Chara	Results
1052–21	June 25	9.5	Vigorous till July 26. Decay till Aug. 23. Vigorous thereafter.	No egg masses till July 29 (4), 30 (2). Larvae matured. No more egg masses during season.
1052–22	June 19	9.5	Vigorous growth all season (Oct. 24).	No egg deposition all season; 65 larvae C. apicalis added (July 14). All died.
1052–23	---do----	9.5	Much decay till July 9. Vigorous thereafter.	Egg deposition 1 (June 27), 1 (July 2). Larvae from first matured, others died. No further egg deposition.
1052–24	---do----	9.5	Maintained vigorous growth all season.	No egg deposition throughout the season.
1052–25	---do----	9.5	Much decay till July 9. Vigorous growth thereafter.	1 egg mass (June 26), larvae matured; 1 (July 2), hatched? No more egg masses.
1052–28	-- do----	------	Chara died down (July 21). Replaced, died (July 30).	Egg deposition took place all through the season and many adults emerged.
1052–29	---do----	9.5	Chara did not become vigorous till July 11. Vigorous thereafter.	Egg masses 1 (June 27), 1 (June 28), 2 (July 2), 1 (July 5). No more during season. Many larvae failed to mature.
1052–42	Aug. 2	9.2	Chara began to decay Aug. 4 and completely died down.	Culex egg masses and larvae through the season. Abundant till Sept. 25.

An examination of the table brings out a most important fact—that wherever there is decay and dying of the *Chara* oviposition by *Culex* species took place almost immediately. In experiments 1052–22 and 24 the *Chara* maintained a vigorous growth throughout the season and no oviposition took place. In those experiments in which considerable decay took place at the beginning, oviposition is recorded and most of the larvae which hatched from the first egg masses matured. Those that hatched from egg masses deposited when the *Chara* was regaining vigor failed, in most cases, to mature. In those aquaria in which growth did not take place (1052–28, 42, 43, 44, and 45) oviposition was excessive throughout the season and immense numbers of adults emerged. Yet despite this density of adults no oviposition took place in those aquaria containing a vigorous growth of *Chara*. Why mosquitoes do not oviposit on water containing a vigorous growth is not known. It may be added that no oviposition took place in our outdoor tubs or wooden troughs where *Chara* growth was vigorous. Oviposition always began when decay started and became excessive as the decay increased.

These and other laboratory experiments appeared so promising that a survey of the local area was undertaken to discover if pools, ponds, lakes, etc., where *Chara* flourished were free from mosquito breeding. Numerous more or less isolated ponds were found with vigorous growths of *Chara* and in practically every case mosquito breeding did not occur. These results were so encouraging that attempts were made during the seasons of 1928 and 1929 to introduce *Chara fragilis* into as wide a variety of known breeding places as possible. This was done and several of these introductions were studied during 1928 and 1929. In order to understand the problems

of *Chara* introductions the breeding habits of our northern species of mosquitoes must be borne in mind. All our *Aedes* species pass the winter in the egg stage, the eggs being deposited throughout the summer on the bottoms or margins of dried-out or greatly lowered pools. These eggs, with the possible exception of *Aedes vexans*, do not hatch till the following spring. All our species of *Culex*, *Anopheles*, and most of our *Theobaldia* pass the winter as adults and oviposit on water during the following spring or summer. It will thus be seen that we have practically only one brood of the *Aedes* species each season, whereas there may be several broods of *Culex*, *Anopheles*, or *Theobaldia* species. There are exceptions to this general summary, but the main thesis holds true for the species under experimentation with *Chara*. In any attempt to introduce *Chara* into pools which dry up during the summer the question of the renewal of growth the following season was problematical. However, for a number of years *Chara fragilis* was found growing in temporary puddles which dried out each season, so it was thought that introductions into similar pools might prove successful. Furthermore, the kind of water which would support *Chara* was not known, and no information was available on the culture, growth, etc., of *Chara* species.

It may be worth while to present the details of two introductions.

Buttermilk Falls pool.—This pool (pl. 6, fig. C.) is rather small and is spring fed. It is about 8 feet in diameter and 2½ to 3 feet deep. *Aedes canadensis* breeds here in great abundance during the early spring and is followed by *Aedes*, *vexans*, *Culex apicalis*, *Culex territans*, and *Anopheles punctipennis*. The main object of the experiment was to obtain a good growth of the *Chara* which might prevent the breeding of the summer species and also prevent the oviposition of *Aedes canadensis* and *Aedes vexans*. The results of this experiment are shown in Table 4.

TABLE 4.—*Buttermilk Falls pool*

Date	Condition of Chara	Results
1928		
Apr. 7		Numerous larvae of Aedes canadensis.
Apr. 9	Introduced 4 pails of Chara	Larvae very inactive, due to cold.
Apr. 18	Not growing	Larvae abundant, growth slow.
May 2	do	Do.
May 13	Growth begins	Larvae abundant; a few pupae.
May 17	Good growth	Pupae numerous.
May 31	do	Anopheles punctipennis, Culex apicalis, a few small larvae.
June 7	Slow growth	Anopheles punctipennis, 2 large larvae. Culex apicalis, a few small ones.
June 13	Vigorous growth	No breeding; larvae and pupae in near-by pools.
June 16 to 28	do	No breeding; near-by pools dry.
July 3	Good growth, but decay area in center.	Culex apicalis, few small larvae; Anopheles, a few larvae.
July 5 to Sept. 6	Vigorous growth, but a central area of marked decay.	Culex apicalis and Anopheles punctipennis bred in fair numbers throughout this period.

TABLE 4.—*Buttermilk Falls pool*—Continued.

Date	Condition of Chara	Results
1929		
Mar. 25	No Chara growth	A few young larvae, Aedes canadensis; near-by pools swarming with this species.
Apr. 2	do	Larvae very scarce; A. canadensis and A. excrucians.
Apr. 20	do	Pool high; larvae very scarce; 50 obtained after much difficulty.
May 1	do	A few large larvae of A. canadensis.
May 11	do	A few small larvae present.
May 23	do	A few small A. canadensis; near-by pools with numerous large larvae and pupae.
May 30	do	A few large larvae. In near-by pools adults had emerged.
June 13	do	No larvae present; near-by pools practically dry.
June 18	do	A few larvae of Culex apicalis and two of Anopheles punctipennis found; near-by pools dry.
July 1	do	No breeding; near-by pools dry.
July 16	do	Do.
Aug. 2 [1]	do	Do.

[1] During the rest of the season there was no growth of the Chara and no breeding took place.

From Table 4 it will be observed that the *Chara* was added on April 9, 1928. At that time larvae of *Aedes canadensis* were very abundant. Growth of the *Chara* did not begin till about May 13, when the first pupae appeared. The development of the larvae was undoubtedly retarded, for pupation took place in near-by pools a week earlier. From June 7 till July 3 there was no breeding in this pool except a few larvae on June 7. In the near-by pools *Aedes canadensis*, *Culex territans*, and *Culex apicalis* were present in both the larval and pupal stages. Early in July the near-by pools became dry, and from then till September breeding took place in our experimental pool. It should be noted, however, that early in July (July 3) a considerable area of decay appeared and this continued throughout the season. Breeding began with the appearance of decay, and this result agrees with that obtained in our experimental aquaria. Another point might be noted: *Aedes vexans* bred in near-by pools but was never found in the experimental pool. The results for 1929 are not very encouraging. The *Chara* did not apparently survive the winter. It is hoped that growth may again appear in 1930. In 1928 the larval density of *Aedes canadensis* was most extraordinary. A few sweeps of a small net brought in nearly 2,000 larvae, and immense numbers of adults emerged. In 1929 it will be seen we had difficulty in obtaining even 50 larvae. Whether this reduction in breeding was due to the *Chara* preventing oviposition in 1928 is difficult to say. Had the *Chara* continued to grow in 1929 we might be justified in concluding that *Aedes canadensis* refused to oviposit where *Chara* grows. However, as compared to near-by pools there was a reduction of mosquito breeding in 1928 and an even more marked reduction in 1929. The near-by pools swarmed with *Aedes*

canadensis, whereas the *Chara* pool contained an extremely small number of larvae.

The woodland pool.—The woodland pool (pl. 7, fig. B) is a large pothole which usually maintains a water supply till late August or September. Here breed *Aedes stimulans*, *A. excrucians*, *A. fitchii*, and *A. punctor*. The larval density is usually very high, and immense numbers of adults swarm during the summer in the surrounding woodlands. Near by are numerous breeding places for these species so that if *Chara* would grow and maintain itself in this pothole we would have an excellent opportunity to test its efficiency. The introductions were made on April 14 and 21, 1928. During the summer of 1928 the *Chara* maintained a considerable growth, but in 1929 none could be found. Though the experimental pool had a high larval density in 1928, there were very few larvae in 1929. Unfortunately the near-by potholes, where there was a high larval density in 1928, had comparatively few in 1929. In fact, this whole woodland area, which usually swarmed with mosquitoes during the summer, had very few during the season of 1929. The reduction was probably due to a salamander (*Diemictylus viridescens*), which swarmed in all the pools during 1928 and 1929. This salamander has been shown to be a voracious feeder on mosquito larvae.

Though numerous other introductions were made, none of them could be followed up in detail. Several new introductions were made in 1929, and I have hopes that some of these may prove more successful. Our failures are due, in all probability, to our ignorance about the biology and cultivation of the *Characeae*. Though I have worked with only one species, *Chara fragilis*, other investigators have employed several other species sometimes with apparent success but unfortunately more often with failure. However, this line of work is directing more and more students to study the underlying factors of larval food, selective breeding habits of mosquitoes and the water conditions which induce or prevent mosquito breeding.

OTHER AQUATIC PLANTS

Little experimental work has been done with other aquatic plants. Zetek (1920) reports that in the Panama Canal Zone anophelines were found breeding in the floating islands and other masses of water lettuce (*Pistia stratiotes*). In Brazil, Bachmann (1921) found that mosquitoes appear to avoid *Pistia stratiotes*, *Myriophyllium brasiliense*, and *Lemna*. He states that *Myriophyllium brasiliense* is being planted along the streams at points where breeding places have been cleared away. In the southern United States, Barber and Hayne (1925) find that anophelines breed amidst water hyacinth (*Piaropis crassipes*).

I did some work with another aquatic plant, *Elodea* (*Phyllotria*) *canadensis* (pl. 7, fig. 2). For a number of years this plant has grown in abundance in pools along a railway embankment. The pools seemed ideal places for mosquito breeding, yet larvae were rarely found. Three experimental aquaria were run under conditions similar to those used with *Chara*. The results are shown in Table 5.

TABLE 5.—*Experiments with Elodea* (*Phyllotria*) *canadensis*

Date	Aquarium 1052–33	pH	Aquarium 1052–34	pH	Aquarium 1052–35	pH
July 10	Set up		Set up		Set up	
July 12	Vigorous growth	9.1	Vigorous	9.2	Vigorous	9.1
July 16	+200 Culex larvae, various.	9.3	+200 Culex larvae, various.	9.3	do	9.3
July 18, 19	16 adults	9.3	22 adults	9.4	+200 Aedes vexans, small.	9.4
July 31	+200 Culex small	9.4	+200 Culex small	9.4	No larvae	9.4
Aug. 9	No larvae, no adults	9.3	No larvae, no adults	9.4	No larvae, no adults	9.4

This table is self-explanatory. How are we going to account for the high death-rate? Furthermore, these aquaria were exposed practically the entire summer to the large numbers of adult mosquitoes that were constantly emerging from our other aquaria, yet in not a single instance did we find an egg mass deposited on them. I have no explanation to offer for the results. If the experiments with oxygen can be successfully repeated with more species of mosquitoes I would surmise that the excessive amount of oxygen given off in minute bubbles by this plant may oxidize the organic wastes too rapidly, destroy any foods in solution or, when ingested by the larvae, interfere with their digestive processes.

The whole problem of selective mosquito breeding involves a fundamental study of aquatic environments. Water which is everywhere so common and abundant, a substance essential to all life, a fundamental necessity to every life process, is one of the most puzzling substances known. Though much has been attempted little fundamental knowledge of water chemistry, of the physicochemical factors of water, of water solutes and their exact constitution or reactions, etc., has been gained. Until we know something more fundamental about the physicochemical factors involved in the relationship of water to life processes we can scarcely hope to make much progress in interpreting the aquatic environments of living plants and animals.

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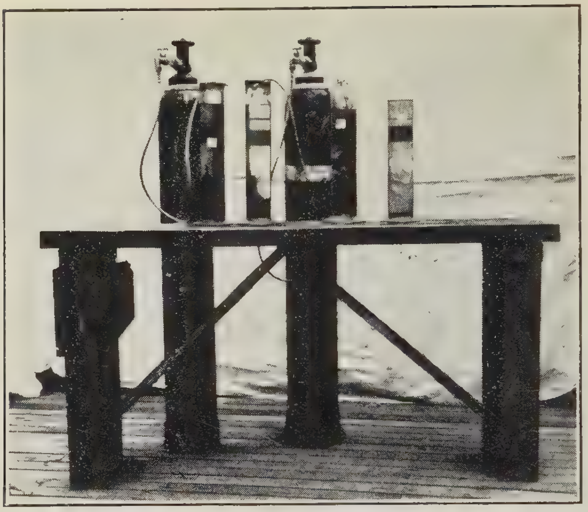
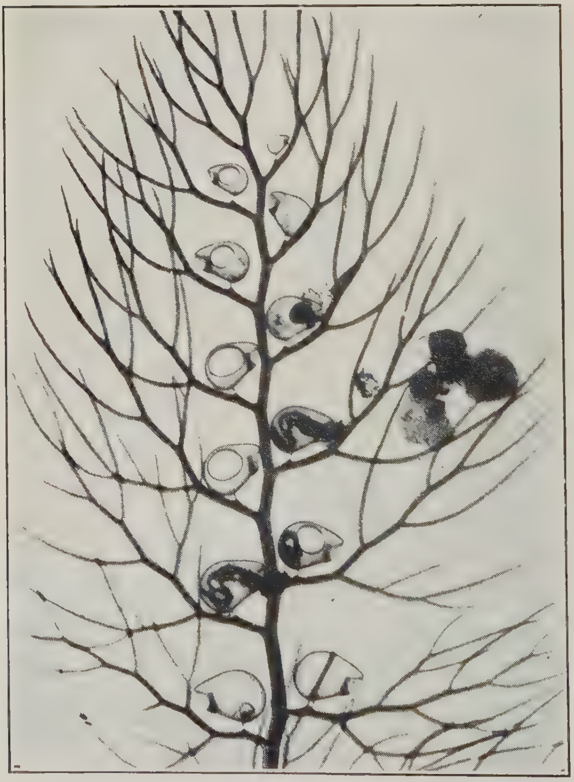
1. Portion of *Utricularia vulgaris*, showing the numerous bladders. Slightly magnified

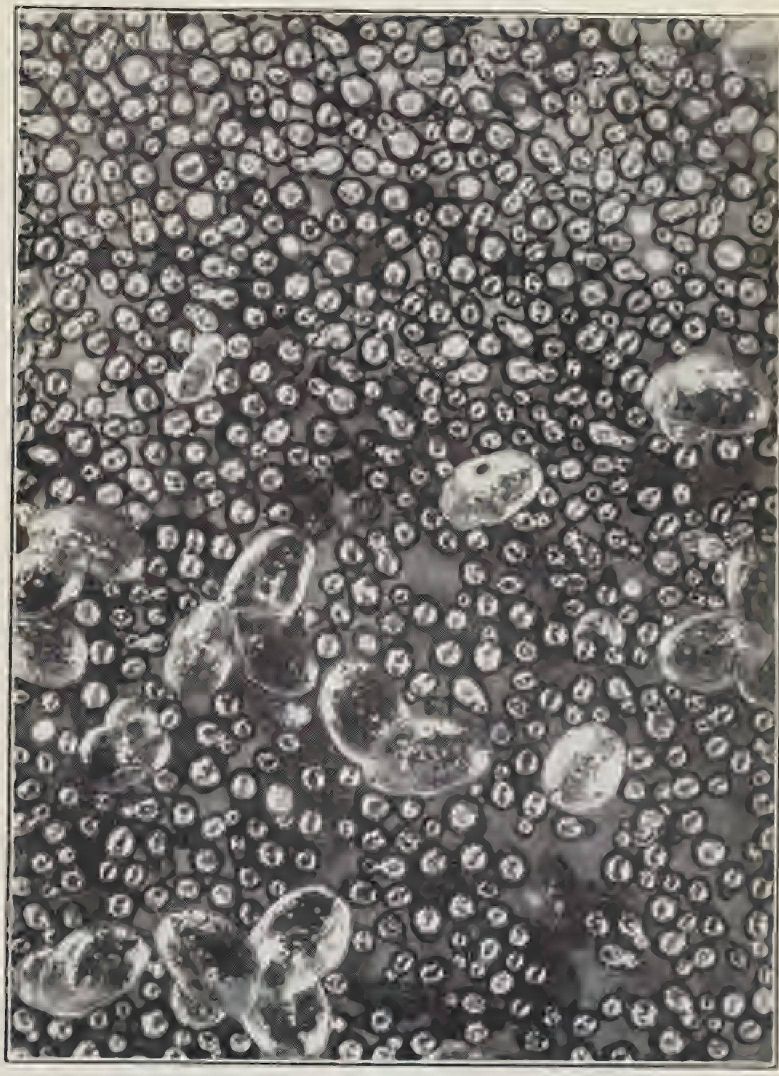
2. Small portions of branches of *Utricularia vulgaris* with bladders which have captured *Brachydeutera argentata*. Note the enormous size of the larvae as compared with the size of the bladders. Magnified about seven times



1. Apparatus for testing the effect of oxygen on larvae. Two cylinders are being treated while two others serve as controls



2. A small portion of a branch of *Utricularia vulgaris*. Ten active bladders are shown and five of them contain mosquito larvae. Magnified seven times

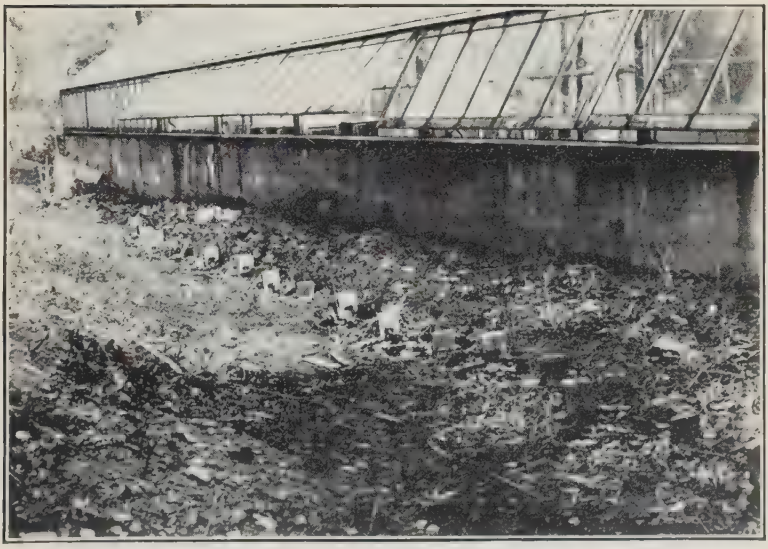


Surface of water covered with *Wollfia punctata* and a few plants of *Lemna minor* (the larger plants). Magnified about seven times

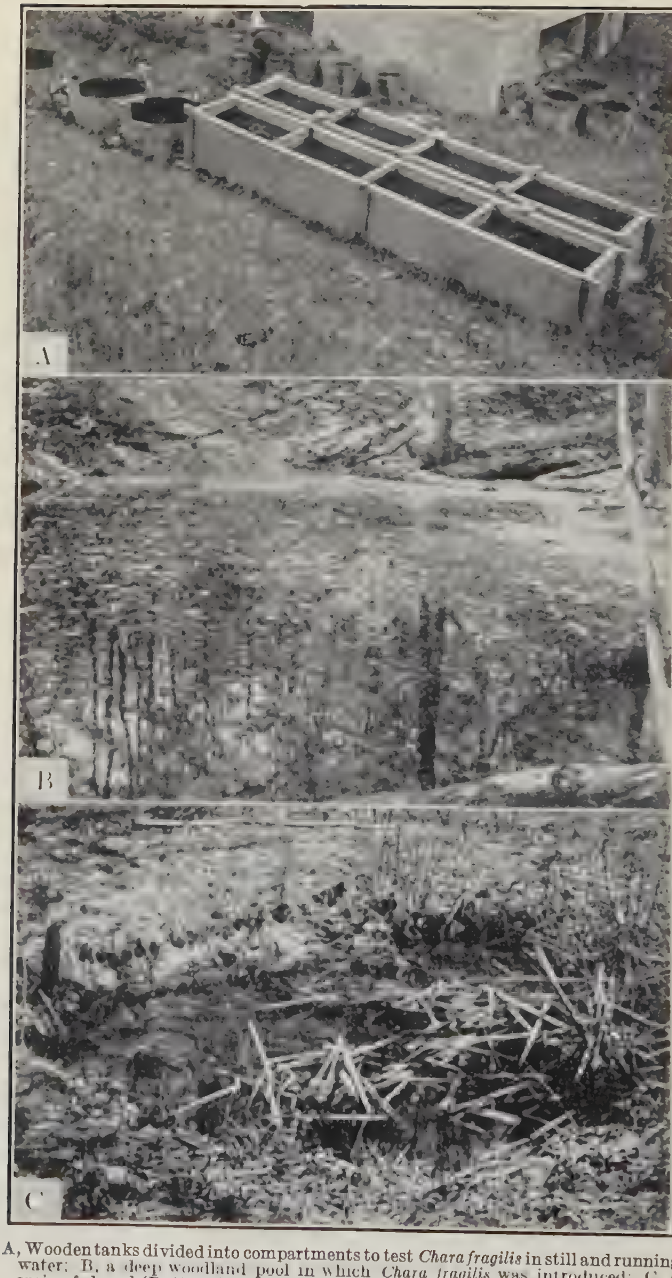
1. A series of aquaria stocked with *Chara fragilis* to test the effect of this plant on mosquito larvae and on oviposition by the adults

2. A pond near Ithaca which for several years has been completely covered with *Lemna* sp. In 1929 the entire surface became suddenly covered with *Wolffia punctata*, a plant closely related to *Lemna*. Mosquito breeding has rarely been observed in this pool and then only scattered larvae

1. A pool with a dense bottom covering of *Chara fragilis*. Along the margins and about the partially submerged logs would seem to be ideal places for mosquito breeding. No mosquito breeding has been found here for the past six years



2. A series of wooden tubs sunk in the ground to test the effect of *Chara fragilis* under out-door conditions. Some of these tubs are used as controls



A, Wooden tanks divided into compartments to test *Chara fragilis* in still and running water; B, a deep woodland pool in which *Chara fragilis* was introduced; C, a spring-fed pool (Buttermilk Falls Pool) planted with *Chara fragilis*

1. A few branches of *Chara fragilis* growing in an aquarium

2. A small portion of *Elodea* (*Phyllotria*) *canadensis* growing in an aquarium. Slightly magnified

OUR FRIENDS THE INSECTS [1]

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There is necessarily such a preponderance of emphasis on the losses man sustains through insects that a statement of the credit the hexapods are responsible for is occasionally desirable to maintain a correct mental perspective in regard to their relation with man's welfare. It is a common and logical principle in educational psychology that instead of setting up a long series of "don'ts" to regulate childrens' conduct we aim to substitute legitimate and desirable activities for those we would prohibit. In a somewhat parallel manner much has been done, and much more may perhaps be accomplished in the future, toward subduing injurious insects by establishing beneficial forms among the undesirable species. Instead of creating a partial biological vacuum in nature by killing insects by artificial methods, we may plant a benefactor where a criminal rules, lest the house that is swept clean and vacated be eventually filled with seven times more devils than at first. Obviously this plan has limitations inasmuch as effective checks do not exist for all pests.

BIOLOGICAL CONTROL

The method of combatting insect pests by the utilization of natural agencies that hold the destructive forms in check is, perhaps, the most fascinating chapter in the history of insect control and at once the least known by the people as a whole. The present attempt is only to prepare a brief, simple account of the growth, methods, and accomplishments of this phase of warfare against insects. The subject stated comprehends other phases of entomology than this, but the present article will be limited to a consideration of our friends, the parasitic insects. The term "parasitic" as used here is defined to include only such insects as live upon other insects, spending a whole stage or more on or in another individual which is designated the host.

[1] Reprinted by permission from the Transactions of the Illinois State Academy of Science, February, 1929.

Ever since man began supplying himself with food by tilling the soil, he has, no doubt, had to fight six-legged enemies of his crops. And when our agrarian ancestors made more or less intelligent observations on them, they probably perceived also, though more rarely, that certain kinds make their living by preying upon, or by eating, the bodies of their own relatives. And as observations in the field of natural history became more purposeful and systematic, the idea of pitting the latter against the former, the benefactor against the foe, probably grew, in a few minds, to a conviction and a personal experiment, and eventually to practice. Doctor Howard (1)[2] tells us that the "gardeners and florists in England for very many years have recognized the value of the ladybirds and have transferred them from one plat to another." But a similar use of parasites is not likely to have been made at that time on account of their small size, and chiefly because of the general lack of knowledge even regarding the nature of their habits. It is not too much to say that no one knew that such a phenomenon as parasitism existed until certain naturalists (1, pp. 16–17) discovered it in the seventeenth century. Aldrovandi, in 1602, is supposed (1, p. 16) to have been the "first to observe the exit of the larvae of *Apanteles glomeratus* L.", a common small wasplike parasite of the imported cabbage worm. But it was probably not until more than a half century later that Vallisnieri (1661–1730) discovered (1, p. 17) "the existence of true, parasitic insects" and the real nature of insect parasitism. "Reaumur (1683–1757) and DeGeer (1720–1778) each studied the life histories of living insects with great care and, among them, worked out the biology of a number of parasites." Ratzeburg observed the bionomics of Hymenoptera parasitic on forest insects, but did not believe that their efficiency could be increased by man.

Hence, although several biologists had become familiar with the fact of parasitism, and apparently considered that man might utilize it in control, the artificial manipulation of parasites was not definitely suggested until after the middle of the nineteenth century. Earlier hints at the feasibility of biological factors for pest control applied to predacious forms, chiefly the lady beetles and ground beetles, whose manner of checking their prey by direct feeding was more easily comprehended generally. Hence, the movement for the use of parasitic insects in what we now call biological control has been begun and carried forward in the past nine decades, and the outstanding ingenious accomplishments of an extensive and practical nature are the work of the past 40 years, and fall mainly within the lifetime of that chief enthusiast for, and sponsor of, the utilization

[2] Numbers refer to list of literature cited at the end of this article.

of insect parasites, Dr. L. O. Howard, who began urging biological control in 1880 and is still engaged in his favorite field.

THE NATURE OF PARASITIC INSECTS

A very small number of the present population of the world is aware of the true nature of the white oval bodies seen so commonly on the backs of certain caterpillars. Aldrovandi, in 1602, supposed them to be eggs which, he probably thought, gave rise to many more caterpillars to eat the rest of his crop. His supposition also implies that he was also unfamiliar with the phenomenon of metamorphosis of moths and butterflies. The nature of these so-called "eggs," their source, and their ultimate end could not be appreciated then, as now, until the fact of metamorphosis among the parasites, and their hosts as well, is understood. Parasitic insects that attack other insects have a common mode of development from the egg to the parent, or adult stage. These friends of ours usually begin life as an egg which the parent places into, on, or near the host. Wasp-like parasites or Hymenoptera have hollow boring instruments, or ovipositors, by means of which the eggs are usually passed into the very bodies of their hosts, whereas two-winged flies or Diptera deposit their eggs on the surfaces of the host, and the responsibility of entering the body of the latter belongs to the young parasite or larva. Certain true wasps, the Tiphiidae and Scoliidae, are parasitic upon beetle grubs in the soil, and their larvae are ectoparasitic, clinging to and feeding only on the outside of their hosts. The Rhipiphoridae, a family of beetles, are also ectoparasites of white grubs, while the little-known minute twisted-winged parasites spend the larval stage in the bodies of wasps and leaf hoppers. When the parasite larvae become full-sized they do, or do not, leave the host, if they happen to be endoparasitic. Wasplike parasite larvae often spin silken cocoons, either in the empty shell of the host, or near by outside: the "maggots" or larvae of flies retain their last skin instead of shedding it as before, and live in it as a covering or puparium. In the puparium or cocoon the larva transforms to the adult stage, the process of transformation being called pupation, and the insect during the transition period is referred to as being a pupa or in the pupa stage. Each of the four stages—egg, larva, pupa and adult—is remarkably different from each of the others, for which reason this mode of development is named complete metamorphosis. On the other hand, insects like the grasshoppers and true bugs have young resembling the adults in form and have only three stages, lacking the pupa. None of the insect parasites of other insects have this type of metamorphosis. Only the larval stage of

parasitic insects feeds upon its host, which ordinarily lives only as long as necessary for the parasite to become mature. The parasites do not feed upon the vital organs of the host, but instead are nourished from the blood which flows about through the open spaces of the host's body, and from the fat body which represents the reserve food supply of the victim. While residing in the host's body the hymenopterous parasite larva retains in its alimentary canal, which is saclike and closed behind, all the wastes from the digestive process. The waste materials are voided concurrently with the last moulting.

It is a significant fact that all parasitic insects attacking others of their class have complete metamorphosis. The larva is no doubt more adaptable to a multitude of circumstances of life than the nymph type of young, such as is present in grasshopper life cycles. While limited in locomotor capacity, the larva has a flexible body capable of entering the soil or boring into and out of a host, and by its tenacious hold on the host, or by virtue of its position in the host, ceases to use, and has long since lost, all the legs it ever had. The parasitic larvae have been engaged in the business of living at the expense of others a long time, as witness the reduction of the legs, antennae, and mouth parts. That they once possessed these organs is suggested by the facts that some nonparasitic relatives still have them and that some parasitic larvae, notably of the ichneumonoid flies, retain their large falcate mandibles in the first larval instar but lose them when they moult the first time. While the nymphs of such external parasites as the sucking lice of mammals and the chewing lice of birds are parasitic, they do not exhibit the versatility in choice of and fitness for life in a considerable variety of host situations such as hymenopterous and dipterous parasitic larvae display. Among the many thousands of species of parasitic insects there is material for a very interesting study of the multiplicity of form and habit changes or adaptations, such as the means by which the parent gets its progeny upon or into the host, how and in what stage the parasite emerges again, and the variety of hosts it may attack. In a single superfamily, the ichneumonoids, we find one species an ectoparasite on caterpillars, another an internal parasite in a hard-shelled, swift-running beetle, a third in a minute, sluggish, soft-bodied plant louse, and a fourth more than a hundred times larger than the former and carrying a set of drills much longer than itself for reaching into the burrow of a tree borer which is the larva of another member of its own order. In fact, one stage or more of some member or members of practically all the 24 orders of insects are probably subject to attack by one species or another of parasitic insects. Furthermore, some parasitic larvae have come to attack other parasite larvae, and

the latter may be subjugated by a third parasite, which, better than anywhere else in the animal world, illustrates well the poem of the fleas that have lesser fleas, and so ad infinitum. We see, then, by these examples that parasitic insects are by no means limited to any particular place, host, or host stage, and still they are so bound to their habits by heredity that they select their hosts within certain group limits and die without progeny if certain hosts, or sometimes a single species of host, are not available. It is this relative uniformity and, furthermore, their limitation to a parasitic life that makes them dependable for use in biological control.

METHODS OF BIOLOGICAL CONTROL

It is necessary to admit at once that the use of parasites to combat their injurious relatives has limitations. Where a native parasite of an indigenous pest already exists and fails to hold its host sufficiently in check, there is not much that has been done to increase the numbers of the benefactor, but new methods may possibly be originated in the future. Their rate of growth is much controlled by weather and the available numbers of the host, and men can scarcely hope to regulate these influences. However, even in the instance of native parasites various means of utilizing them are known or may be developed. It is a well known fact that winters reduce the numbers of parasites considerably below their status of the previous year. The host is likewise reduced, oftentimes, but the parasite can not reproduce extensively until its host is first plentiful. Consequently, the host is free to do more or less damage in the first months of the growing season, whereas the parasite requires a month or two to " catch up " or reach effective numbers. At present, projects begun in California are under way in several States of this country to develop an abundance of the egg parasite (*Trichogramma minutum*) of certain moths in laboratories during the early spring. They are then released in orchards for the control of the codling moth, or in southern fields to hold the cane stalk borer or celery leaf tyer in check, while the outdoor parasites are building up a controlling number. The method of securing the parasite in plenty is to use the Angumois grain moth which reproduces in stored grains indoors under warm conditions during the early spring and whose eggs can, therefore, be secured in large numbers. These eggs are exposed to the adult parasites which deposit their eggs into those of the moth. The life cycle of the parasite is short, hence a good number of generations is produced annually and many thousand individuals are reared quickly with proper mechanism and management.

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The variation in the beginning of the growth period from the north to the south extreme of the United States amounts to several weeks. For example, between southern Ohio and Illinois and the northern boundaries of these States there is, in the instance of some crops, a difference of three weeks. As an illustration, let me cite the instance of the imported cabbage worm and its *Apanteles* parasite in Ohio. In the Muskingum Valley of that State early cabbage harvest is begun by the 4th of July, whereas some cabbages are only being set into the field in the north part at the same time. The chief pest of cabbage there is the imported cabbage worm, whose very efficient parasite was intentionally introduced from Europe many years ago to check the worm. In the first two generations the worm gradually develops injurious numbers, but the parasites also multiply rapidly. By the time that the cabbage crop is removed the parasites dominate the situation, but must soon be weakened in numbers again because the host grows scarce due to parasitism and many thousands of parasites die without reproducing. At this time the worm is probably doing its worst damage 200 miles north. Valuable cabbages grown in the vicinity of large cities like Cleveland and Toledo are probably being injured, or artificial control may be practiced. Inasmuch as many thousands of the parasite may be gathered in a few days at Marietta, it would seem feasible to ship or carry such for release in the north parts to greatly supplement the work of the individuals present there and perhaps prevent severe damage to the crop and possibly avoid the extensive use of insecticides.

Perhaps the most feasible mode of favoring parasites of insect pests is to modify slightly the application of certain other insect control measures. When a pest is known to possess one or more effective parasites, wholesale slaughter of the hosts should be avoided in order to permit the parasites to increase. For example, the large green injurious tomato and tobacco horn worms are freely parasitized by a small wasplike species whose mature larvae issue through the back of the host and spin their white cocoons there. When such cocoons begin to appear, many caterpillars could easily be assembled and placed in a screened cage, from which the parasites can go forth but which retains any moth that might have escaped the parasite. Many other insects might be kept at a minimum in this manner or a modification of it without excessive costs, if their parasites were better known and this method of biological control were studied with reference to them. Probably no other plan for the use of parasites has been more frequently suggested in earlier times.

In spite of careful State and interstate inspection service to prevent the spread of insect pests, some of these inevitably penetrate into new territory. Trade within and between States has been

instrumental in transporting or disseminating such insects. It occurs also that their parasites are not spread at the same time, permitting the host to multiply to unprecedented numbers and to greatly increase damage. The common asparagus beetle, a European species, is capable of causing severe loss under favorable conditions. In the East it is in part checked by a chalcid egg parasite, which, as far as known from several attempts to locate it in Ohio and Illinois, has not followed its host into all its present geographical range in America. On the other hand, the squash bug, a native species of general distribution, seems to be without its egg parasite in Illinois, whereas such a species is known to exist in the eastern States. Providing a more extended study of these and other insects should confirm such findings as the above, the artificial spread of the parasites of these pests might be undertaken, and the parasites could probably be established with little cost or difficulty. Deserts, mountain ranges, or large bodies of water may act as deterrents or barriers to the spread of parasites into the areas which may be reached with relative ease by their hosts on account of their better equipment for long-distance travel.

The most obvious as well as most productive use that can be made of parasites is based on the fact that some of our plant-eating insects are of foreign origin. These have usually come to our country without their natural enemies, hence multiply without limitations and constitute some of our " millionaire " insect pests. A few major examples are the European corn borer, the gypsy and brown-tail moths, the Japanese beetle, the codling moth, and the imported cabbage worm. It has been recognized for about 40 years, since the gypsy-moth problem became acute, that one of the fundamental steps to take in attempts to control such imported and liberated pests is to study them in their native situations. These studies soon revealed that the insects were usually of relatively small importance in their old homes and that this difference in their status was caused by the work of one or more parasites. Thus was suggested the idea of bringing these parasites to this country, where it was hoped they would eventually perform the same good service as in their native lands. The result is that many species of parasitic insects have been introduced and successfully established here in the last four decades and with more or less of the desired effect.

The procedure in such introductions naturally varies much due to the difference in habits of the parasites and their hosts and the advantage taken of earlier experiences for development of better methods of handling them. But the general essentials are as follows: Specialists in parasitic insects are sent by the States or usually the Bureau of Entomology of the United States Department of Agricul-

ture to the native abode of the pests and their parasites. These men go for a year, or several years, or more, and establish laboratories in a crucial area where the host and its enemies are carefully studied before shipments of parasites to this country are attempted. Such studies are in the nature of bringing out facts that will lead to the intelligent manipulation of the parasites when they are transported, and even more for the sake of ascertaining whether the beneficial primary parasite may have parasites of its own, or secondary parasites, which, if introduced, would more or less impair the efficiency of the primary species. By means of laboratory technique the secondary parasites may be eliminated and a quantity of free primaries obtained for shipment. Other species have no secondary enemies. Native men, women, and children are employed to collect the parasitized insects desired and deliver them at the laboratories. After their habits and life histories are studied, numbers of them are packed for shipment. They may be in the egg, larva, pupa, or adult stage when sent, the stage preferred being determined by the knowledge man has gained of the ways of the parasite and its host. Frequently the parasite is a larva in the egg or other stage of the host, or in a cocoon of its own, out of, or in, the hosts' body or cocoon. A convenient time to send some parasites is in a cold season, when they are naturally dormant due to low temperature, or if sent in a warm season they have frequently been stored in refrigerators at temperatures of 40° to 50° F. on ship to prevent further development before they reach their destination. Or food and hosts may be supplied in cages to enable the parasite to continue its growth in a normal way in transit. If the parasite larva be in the host when sent, it may reach the pupa or even the adult state by the time it arrives after a journey lasting from one to two weeks.

If the parasites make the trip successfully, they are next placed in a laboratory to study further their habits, to determine whether hyperparasites may be present, and to develop large numbers for liberation. The breeding is done in many ways, depending again on the species concerned, and a considerable variety of cages and technique are employed. The hosts are provided in these cages to allow the parasites to multiply upon them. Usually when thousands are developed, they are taken, at the most opportune time known, to selected spots where the host is abundant, and where the environment is otherwise favorable to the survival of the parasite. Thereafter the parasite is dependent entirely on its own persistence in finding its hosts and in resisting the climate and other untoward influences. Sometimes our own parasites attack it, even when its native enemies have been left behind. Probably less than half the species introduced from other countries are established, or, if established may

be of minor importance as factors in host control. Success depends on so many influences that the entomologists concerned need have intimate knowledge of every phase that composes the parasite's environment as well as of its habits and development. However, in spite of failures due to inadequate facts, the specialists who are close to the work are optimistic for the future, and Dr. L. O. Howard (2, p. 282) says "work of this kind is in its infancy, and its possibilities are great." It is necessary to point out again, however, that this method of combating insect pests is not advocated as a panacea for all insect troubles, and can not be regarded as a solitary substitute for any or all other methods now in use.

INSTANCES OF PARASITE TRANSPORTATION

The transportations of parasitic insects have by no means been to the United States alone, although this country started this type of work on a large scale. Porto Rico imported experimentally in 1911–1913 from our own State certain wasp parasites (*Tiphia* sp.) for the control of the sugar-cane grubs which are related to the Illinois corn-root destroying white grubs.

The mulberry scale threatened the silk industry in Italy (3), but it was almost completely freed of this pest by a minute parasite (*Prospaltella berlesei*) established there from America and Japan.

Australia inadvertently received the woolly apple aphis, a notorious louse pest of the apple, because its covering of woolly secretion protects its body against ordinary contact sprays. The apple industry had prospered greatly in that favorable country until the arrival of this aphis. Professor Tillyard, of Australia, with the aid of our entomologists, received importations of a small wasplike parasite from the United States where it holds this pest in check. The parasite is flourishing in Australia, and, as a result, the apple industry is doing the same.

The larch forests of Canada have been severely injured by an imported sawfly, whose larva eats foliage. About 14 years ago, one of its foreign parasites was established, and by gradually increasing has now practical control of the host, the last reports indicating over 70 per cent mortality due to the parasite.

The Hawaiian islands present a peculiar biological situation in that they originally harbored few native crop pests. By international commerce the sugar cane leaf hopper became established there, and created heavy losses amounting in 1903 to $3,000,000. By 1906 some species of egg parasites obtained in Australia were multiplying rapidly, and after 10 years Doctor Howard (3, p. 7) found that the leaf hoppers had been reduced to practical insignificance. This is only an example of numerous other instances of com-

plete success with imported parasites in Hawaii. But this case is not typical of most introductions into the United States and elsewhere, for the reason that parasites taken to Hawaii have no native secondary enemies awaiting them, hence multiply with extraordinary rapidity.

Extensive attempts have been made with varying success to establish foreign parasites of imported pests in the United States. California has always been a leading State in experiments with biological control, and (4) " because of the spectacular results of the introduction of *Vedalia* the Australian ladybird, in the early days of California horticulture, the general public was inclined to favor this method of control to the exclusion of all others." The black scale " is still the most important pest of citrus in the State," and effective natural enemies are still being sought.

From 1911 to 1913 (5) the cocoons of the parasite of the alfalfa weevil were sent to Utah where alfalfa culture was damaged by this snoutbeetle. By 1922 the parasite " was practically covering the weevil territory," and parasitism sometimes reached 85 to 90 per cent or more.

Generally, the appearance of a new insect pest of importance in this country is a signal for the beginning of a search for its parasites. In the New England States thousands of acres of woodlands, and shade and forest trees have been defoliated at various times since 1889 by the caterpillars of the gypsy and brown-tail moths, both of which are of European origin. Than this there is no more extensive instance of damage by introduced pests and there is scarcely an example of a more far-reaching attempt to control such pests by its introduced parasites. Since 1905 (6) " over 60 species of parasites " of these enemies of trees, " including predacious bettles, have been imported from Europe and Japan." Mr. Burgess indicates that many attempts failed, for " of this number 16 species have become established in New England. One-half of these have not become very abundant and are probably of slight importance." The damage, however, decreased " with more or less regularity until 1924, when only a small number of localized areas were defoliated." Observations over many years indicate that the number of parasites fluctuates with the result that occasional injury of more or less extent may be expected in the future. The same consequences will normally result in the instance of any other pest for whose control parasites are chiefly employed. The ideal of parasite importation in this and other instances is perhaps to find and establish a series of parasites, one or more attacking each stage of the host, and thus developing a sequence that will strike the host at various seasons of the year and perchance effect an adequate control in spite of varia-

tions in factors governing host and parasite abundance. However, this point of view has been criticized, and certain other plans may be more effective.

While the gypsy and brown-tail moths were the occasions for the first large-scale biological control project of the United States Bureau of Entomology, others of large dimensions have since been instituted. The Japanese beetle is a relative of our common May beetles or white grubs. It was first seen in this country in New Jersey in 1916 and the grubs in the soil wrought havoc on lawns, meadows and golf courses since that date, while the adults have done likewise to foliage, flowers, and fruits in general. In 1920, the study of its natural enemies, including parasites, was begun in Japan (7), and up to January, 1927, nine species of parasites were found there and in Chosen (Korea). One of the three tachinid flies parasitizing the adult beetle frequently destroys from 50 to 100 per cent of its host and this species, among other parasites, has been introduced into this country. Six other species attack the host in the larval stage.

Among other pests of primary importance are the Mexican bean beetle, the Oriental fruit moth, and the European corn borer, all of which have occasioned the investigation of their native parasites, but those of the corn borer, the worst threat we ever had on our corn crop, deserve special mention. Although six two-winged (Diptera) parasites and seventeen wasplike species (Hymenoptera), all native, have been found attacking the eggs, larvae, and pupae here, "the combined parasitism" by these species "has totaled less than one per cent of the larvae and pupae collected each year" (8). The native parasites are therefore "practically negligible except in the case of the sporadic egg parasite, *Trichogramma minutum* Riley" (8). Eight species of Diptera and Hymenoptera that parasitize the corn borer in Europe had been liberated in the infested area of the United States up to February, 1927. Two of these (*Microgaster tibialis* Nees and *Exeristes roborator*) had been recovered incidentally at that time. It can not be predicted what the status of the imported species will be in the future. Ten years or more are sometimes necessary for a normal adjustment of parasites to their new surroundings and to reach their maximum efficiency, providing they become established at all. It is generally believed that parasites of the corn borer can not be expected to become an adequate check alone on this pest, the chief factor operating against a high proportion of mortality seeming to be the habit of the host of feeding sheltered within the corn stalk most of the time during the stages susceptible to attack.

The amount of hope to be placed in the method of control by the use of entomogenous insect parasites is obviously various, according

to the species considered. But whether they are in themselves sufficient to keep to an insignificant minimum the economic loss occasioned by their host, or must be supplemented by other methods of control, our friends, the parasitic insects, constitute one significant ally of man. Their importance does not permit them to be omitted from any program of control for foreign introduced pests, and furthermore, it may be truthfully said that the appreciation of the possibility of their use against native pests has probably only begun.

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EVOLUTION OF THE INSECT HEAD AND THE ORGANS OF FEEDING

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The organs of feeding in nearly all animals are intimately associated with the head, because it is the head end of the body that goes forward in the usual modes of progression and is, therefore, the first to come into contact with the food. The head is at the anterior end of the body because the head was probably differentiated primarily as the sensory pole of the animal. The primitive head did not necessarily contain the mouth, and in some of the worms the mouth is still located near the middle of the ventral side of the body.

The head of an insect is a composite structure formed of several of the primitive anterior body segments. The mouth is located on the head and the principal external organs of feeding are appendages of some of the segments associated with the mouth. The head segments are so closely united in the cranium-like head capsule that the primitive segmental areas are no longer discernible. The mouth appendages were undoubtedly at one time legs, but they have become so altered in adaptation to the feeding function that the primitive leg structure is seldom apparent in them and is often entirely obliterated. It is very difficult, therefore, to decipher the evolution of the insect head and the organs of feeding from a study of adult insects, and, though the development of the embryo throws some light on the subject, embryological evidence is always subject to various interpretations. Furthermore, the oldest known insects of the geological records are so much like modern insects that paleontology gives little assistance in a study of the origin of insect structures. Probably no other group of animals have so effectively covered their evolutionary tracks as have the insects.

It is an easy thing for anyone to becloud his intentions, or to create uncertainty as to his future course of action, but to keep his past a secret is quite a different matter. It often happens that information on an obscure subject is more easily acquired in a roundabout way than by going direct to the object of investigation. For

example, if we should wish to know something about some particular person, we might find on an interview with him that he had forgotten many things of his past, which his relatives, with better memories in such matters, would readily divulge, if approached in the right way. So it is in the study of insects—their relatives in many cases will reveal things about them that we should never be able to get from the insects themselves. One reason why our understanding of insects is not all that it might be is that entomologists have been too diffident in the matter of making intimate acquaintances with arthropods other than insects. A formal letter of introduction to them, therefore, may not be out of place here, especially since the members of the arthropod classes will not be familiar to all readers under their scientific names.

The Arthropoda are the "jointed-legged" animals, so named not because other animals do not have jointed legs but because the legs of arthropods are so conspicuously jointed. The familiar arthropods are the crabs, lobsters, crayfish, spiders, millipedes, centipedes, and insects. Associated with these forms, however, are many obscure relatives known for the most part only to zoologists. The following table will show briefly the way in which the Arthropoda may be classified according to their structural characters.

CLASSIFICATION OF THE ARTHROPODA

I. Chelicerata.—Arthropods in which the principal feeding organs, or chelicerae, are appendages of the first postantennal somite, and generally have the form of a pair of small pincers. The legs often have a segment, the patella, interpolated between the femur and the tibia.

Eurypterida (extinct fossil forms).
Xiphosura (horseshoe crabs).
Pycnogonida (spiderlike, marine arthropods).
Arachnida (spiders, scorpions, ticks, mites).

II. Mandibulata.—Arthropods in which the principal feeding organs, the mandibles, are appendages of the second postantennal somite, and have typically a jawlike form. A patellar segment is never present in the leg.

Crustacea (shrimps, crayfish, lobsters, crabs, sowbugs).
Symphyla (small, centipedelike relatives of the diplopods).
Pauropoda (relatives of the the diplopods having only a few legs).
Diplopoda ("thousand-legs," or millipedes).
Chilopoda (centipedes).
Hexapoda (proturans and insects).

The insects comprise two principal groups, the Apterygota, or primitive wingless insects, and the Pterygota, including all winged

forms, and wingless species that are undoubtedly descended from winged ancestors. The Onychophora (*Peripatus* and related genera) are sometimes classed with the Arthropoda, but these curious, many-legged animals are more evidently related to the annelid worms. The latter include the well-known earthworms and many worms that live in the ocean, all comprised in the Annelida, which also we shall have occasion to mention frequently in the following discussions.

I. GENERAL STRUCTURE OF THE HEAD AND FEEDING ORGANS

The head of an animal may be defined as the specialized anterior part of the body. The organs of feeding are, primarily, the mouth and whatever part of the alimentary canal serves for the ingestion of food; and secondarily, external structures functionally associated with the mouth. In insects, as we have seen, the *head* is a consolidation of several anterior body segments; the *mouth* is an

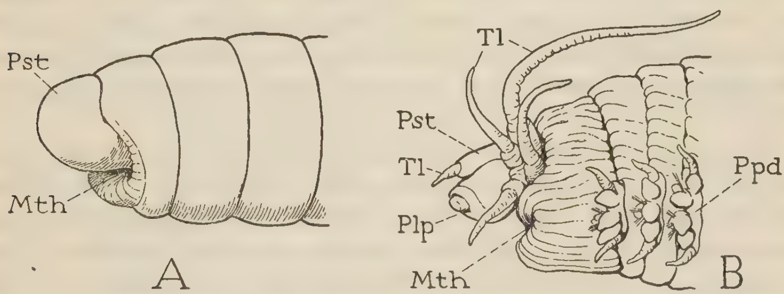

FIGURE 1.—Head structures of annelid worms

A, earthworm. B, marine worm, *Nereis virens*. *Mth*, mouth; *Plp*, palpus; *Ppd*, parapodium; *Pst*, prostomium; *Tl*, tentacles.

aperture on the ventral wall of the head; the ingestive part of the alimentary canal is the *stomodeum;* the external organs of feeding are appendages and lobes of the head associated with the mouth, known collectively as the *mouth parts.*

Cephalization.—A head is a prominent feature in the organization of nearly all animals; but all animals do not have a head to the same degree, which is to say, cephalization has not progressed equally far or accomplished the same results in all cases. The term *cephalization* (from Greek κεφαλη′, a head) means the structural specialization of the anterior end of the body for whatever purposes the animal has found it advantageous to have its anterior end physiologically specialized. Anatomical cephalization assumes that in the evolution of any group of animals there was a time when the ancestors of the group did not have a head or that the primitive head was nothing more than the pole of the body directed forward during progression. The habit of moving always with the same

end forward, therefore, first established the distinction between a head end and a tail end in the animal, and was the precursor of cephalization.

A good example of well-established physiological differentiation between the two poles of the body, but with a minimum of anatomical cephalization, is seen in the Annelida, or segmented worms (earthworms and their marine relatives). The "head" of these worms consists only of a small apical lobe of the body, called the *prostomium* (fig. 1, *Pst*), which is highly sensitive and gives rise from its ectoderm to the first ganglion of the central nervous system, but it does not bear feeding organs, and the mouth (*Mth*) is located behind it. The annelids show also a good example of simple segmentation of the body, since the entire length of the worm behind the prostomium is divided by circular grooves into short body parts, or *somites*, commonly termed "segments." The mouth (*Mth*) lies in the ventral wall of the first segment, or between this segment and the base of the prostomium. The earthworms lack segmental appendages, but some of the marine annelids have a series of movable flaps along each side of the body, called *parapodia* (fig. 1 B, *Ppd*).

The Arthropoda are segmented animals having much in the basic plan of their organization that resembles that of the Annelida; but in most respects they are far more highly evolved animals than are the segmented worms, and their complex segmental appendages, as we have seen, are characteristic features of their anatomy. In the arthropods, cephalization has progressed so far that the head consists not only of the prostomium but of a varying number of the anterior segments of the body, all intimately combined in a composite head structure. The head, moreover, retains most of the appendages of its component segments, which are structurally modified for various purposes, and its united nerve ganglia form specially developed nerve centers.

The degree of cephalization, however, varies much even within the Arthropoda. A relatively simple head occurs in many of the Crustacea, in which the head consists of not more than three primitive body segments combined with the prostomium (figs. 2 A, 16 A, *Prc*). A head of this type of structure bears the eyes (*E*), two pairs of antennal appendages (*1Ant*, *2Ant*), the mouth on its under surface, and a median prostomial lobe (*Lm*) before the mouth. The jaws (*Md*) and other appendicular organs that function in connection with feeding are carried on the body segments immediately following the head. In some other crustaceans, however, the segments of the feeding organs also are added to the head, and in such cases the entire head complex possibly contains as many as six or seven segments.

The Diplopoda and Chilopoda have likewise a composite head structure in which, so far as known, six segments are united in a craniumlike head capsule. The insects have a highly individualized head (fig. 2 B), in the composition of which there appear to be six segments, or possibly seven. In the Chelicerata, on the other hand, most of the members have no distinct head, but this does not mean that they preserve the primitive annelid condition; on the contrary, in most of the Chelicerata cephalization has progressed so far that not only the segments of the true head region, but also the segments of the leg region of the body as well are all united into a large structure known as the *cephalothorax*.

The insect head.—A typical insect head (fig. 3 A) is a craniumlike capsule supported on the body by the membranous neck (*Cv*). Its anterior lateral and dorsal walls are strongly sclerotized, as is also

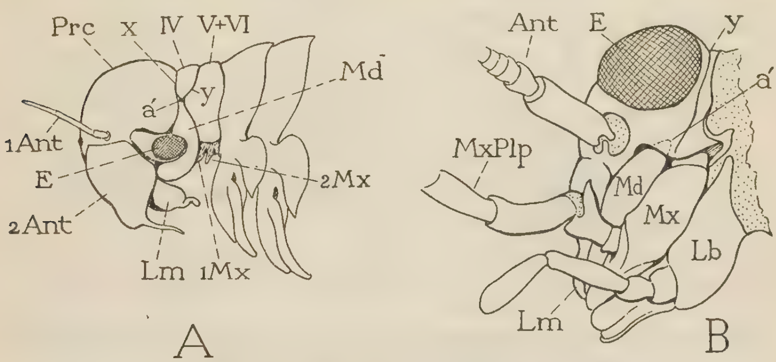

FIGURE 2.—Examples of different degrees of cephalization in adult arthropods

A, head of a phyllopod crustacean, *Eubranchipus*, in which the principal part of the head is the protocephalon (*Prc*), bearing the first antennae (*1Ant*), second antennae (*2Ant*), compound eyes (*E*), and labrum (*Lm*), followed by a distinct mandibular segment (*IV*), and the united maxillary segments (*V+VI*). *B*, head of an apterygote insect, *Machilis*, in which are combined the protocephalon, and the mandibular and maxillary segments.

whatever there may be of a posterior wall surrounding the attachment of the neck. The ventral wall (B) is so cramped between the bases of the head appendages as to be scarcely recognized as the floor of the head, and a large part of it is bulged out in the form of a median lobe, which is known as the *hypopharynx* (*Hphy*).

The exposed, hard-walled part of the head is often called the "epicranium," but since different writers use this word with different restrictions, the term *cranium* will serve just as well, or better, in a general sense to designate the skull-like part of the head in distinction to the appendicular parts and the ventral area between the bases of the appendages. From the facial aspect of the head arise the *antennae* (fig. 3, *Ant*), and on the sides are located the *compound*

eyes (*E*). In many insects there are three simple eyes, distinguished as *ocelli* (*O*), placed on the top of the head or on the upper part of the face. From the lower part of the face there hangs before the jaws a free transverse lobe, the *labrum* (*Lm*). Behind the labrum are suspended from the lower lateral margins of the cranium three pairs of feeding appendages, or *gnathopods* (*Md*, *1Mx*, *2Mx*), which are legs transformed into organs for manipulating and chewing the food. The cavity of the head communicates with that of the body by an opening in the posterior wall of the cranium, usually of large size (figs. 9 B, 13, *For*), commonly called the *occipital foramen*, though by analogy it corresponds with the *foramen magnum* of a vertebrate skull.

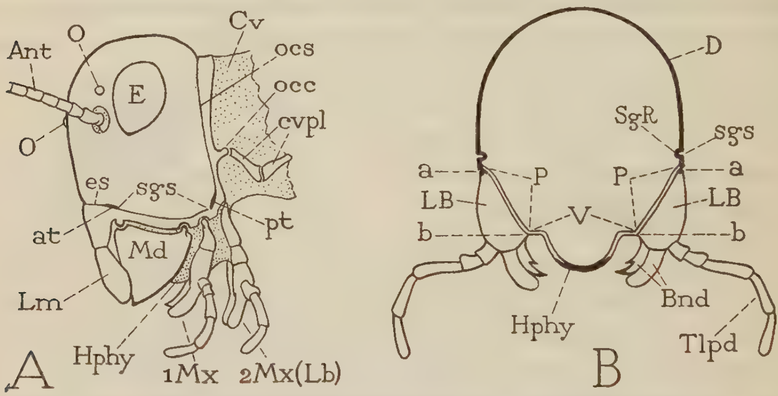

FIGURE 3.—Diagrams showing the general structure of an insect's head and the relations of the mouth parts to the cranium

A, lateral view. B, transverse section. *a*, dorsal articulation of basis of a gnathal appendage with lower edge of cranium; *Ant*, antenna; *at*, anterior tentorial pit; *b*, ventral end of basis; *Bnd*, basendites, or mesal lobes of appendage basis; *Cv*, cervix, or neck; *cvpl*, cervical sclerites; *D*, dorsum; *E*, compound eye; *es*, epistomal suture; *Hphy*, hypopharynx; *LB*, basis of the appendage; *Lb*, labium; *Lm*, labrum; *Md*, mandible; *1Mx*, first maxilla; *2Mx*, second maxilla; *O*, ocelli; *occ*, occipital condyle; *ocs*, occipital suture; *P*, *P*, pleural areas; *pt*, posterior tentorial pit; *SgR*, subgenal ridge; *sgs*, subgenal suture; *Tlpd*, telopodite (palpus) of appendage; *V*, venter.

If we analyze a cross-section through the posterior part of the head (fig. 3 B) in terms of the structure of a body segment cut transversely, we arrive at the following results. The cranial wall above the dorsal articulations of the appendages (*a*, *a*) is the dorsum (*D*), and its sclerotization represents the tergum of a body segment; the ventral wall (*V*) between the lower ends of the appendage bases (*b*, *b*), including the hypopharynx (*Hphy*), is the venter, or region of a body segment that contains the sternum; the ventrolateral areas (*P*, *P*), in which the appendages are broadly implanted correspond with the so-called pleural areas of a body segment; and finally, the appendages themselves represent a pair of legs, each with an enlarged

basis (LB) bearing a pair of mesal lobes (Bnd), and a reduced, segmented distal shaft ($Tlpd$) corresponding with the part of a leg beyond the coxa.

The neck, or *cervix* (fig. 3 A Cv), is a membranous cylinder uniting the head with the first segment of the thorax (prothorax). Usually there are two small neck plates, the *lateral cervical sclerites* ($cvpl$), in each side of the neck serving to link the head with the thorax and to control the movements of the head on the body. The first sclerite of each pair articulates with an *occipital condyle* (occ) on the posterior rim of the cranium; the second articulates with the anterior margin of the first lateral plate (episternum) of the prothorax. In some insects there is only one plate on each side of the neck, and a few insects have no cervical sclerites, while, on the other hand, there may be several accessory neck plates, especially in the lateral and ventral walls of the neck.

The mouth parts.—The external feeding organs of insects are known collectively as the "mouth parts." They include the labrum (fig. 3 A, Lm), the hypopharynx ($Hphy$), and the three pairs of gnathopods. The first pair of gnathopods, or *mandibles* (Md), are typically, in biting insects, strong biting and chewing jawlike organs; the second pair, or *first maxillae* ($1Mx$), known as "the maxillae" in insects, are usually more leglike than either of the others; those of the third pair, or *second maxillae* ($2Mx$), are always united with each other in insects to form the single organ called the *labium* (Lb).

The mouth parts undergo innumerable modifications of form in the various orders of insects by way of adaptation to different ways of feeding or to feeding on different kinds of food. They always preserve their basic structure and their fundamental relations to the head, but the ways in which the primary structure and relationships have become obscured create many perplexing problems for entomologists to solve. Insects that feed by biting off, masticating, and swallowing pieces of their food material undoubtedly retain the more primitive type of mouth parts, and a study of the head and the organs of ingestion in species of this kind, known as the *biting and chewing* insects, will serve as a foundation for the study of the more highly specialized types, whose feeding habits are mostly *sucking*, or *piercing* and *sucking*.

The mouth and the stomodeum.—The mouth of an insect is a median aperture in the ventral wall of the head immediately behind the base of the labrum (fig. 4, Mth). The space between the mouth parts is often erroneously called the "mouth cavity," and sometimes the "buccal cavity," but morphologically it is entirely outside the alimentary canal, and is only an external space partially inclosed by the mouth parts. It should be termed the *preoral cavity* (PrC).

The true *buccal cavity* of the insect is the anterior part of the stomodeum lying immediately within the mouth (fig. 4, *BuC*). It is to be identified by the attachments of its dorsal dilator muscles (*dlbuc*) on the head wall, the origins of these muscles being always on the lower part of the face known as the clypeus (*Clp*). Ordinarily the buccal cavity is small, but in some insects it is greatly enlarged to form a sucking pump.

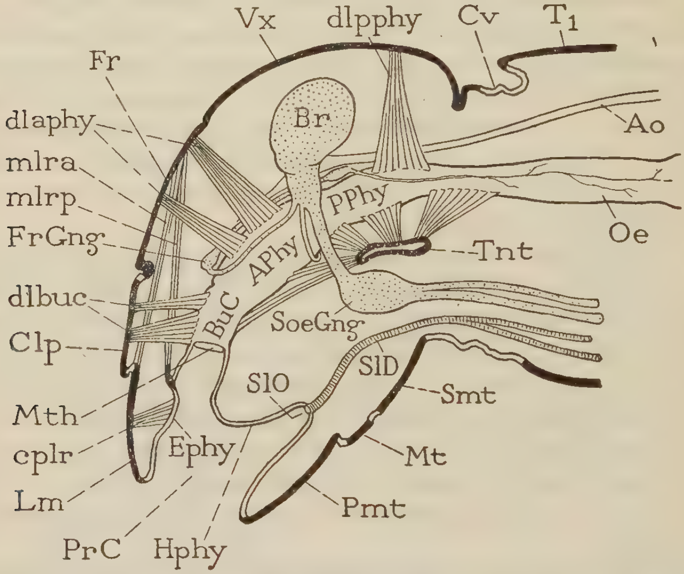

FIGURE 4.—Diagrammatic median vertical section of an insect's head *Ao*, aorta; *APhy*, anterior pharynx; *Br*, brain; *BuC*, buccal cavity; *Clp*, clypeus; *cplr*, compressor muscles of labrum; *Cv*, neck; *dlaphy*, dilator muscles of anterior pharynx; *dlbuc*, dilators of buccal cavity; *dlpphy*, dilators of posterior pharynx; *Ephy*, epipharynx; *Fr*, frons; *FrGng*, frontal ganglion; *Hphy*, hypopharynx; *Lm*, labrum; *mlra*, anterior labral muscle; *mlrp*, posterior labral muscle; *Mt*, mentum; *Mth*, mouth; *Oe*, oesophagus; *Pmt*, prementum; *PPhy*, posterior pharynx; *PrC*, preoral cavity; *SlD*, salivary duct; *SlO*, opening of salivary duct; *Smt*, submentum; *SoeGng*, suboesophageal ganglion; T_1, tergum of prothorax; *Tnt*, tentorium; *Vx*, vertex.

Following the buccal cavity is the *pharynx* (fig. 4, *APhy*), a specialized part of the stomodeum usually ending between the nerve connectives that unite the brain (*Br*) with the suboesophageal ganglion (*SoeGng*). The dilator muscles of the pharynx arise on the head wall above the region of the clypeus and on the tentorium (*Tnt*). In certain insects, particularly in Orthoptera and Coleoptera, the pharynx extends beyond the nerve connectives, and its two parts, separated by the nerve ring, are then distinguished as the *anterior pharynx* (*APhy*) and the *posterior pharynx* (*PPhy*). In some suck-

ing insects the pharynx and not the buccal cavity forms the sucking pump; in still others the pump is a bucco-pharyngeal structure.

Beyond the pharynx the stomodeum generally narrows to a tubular *oesophagus* (*Oe*). Posteriorly, however, the oesophagus often widens into a *crop*, and in some insects the crop occupies almost the entire length of the oesophageal region. The stomodeum terminates in a *proventriculus*, from which a valvular fold of its wall projects into the stomach, or *ventriculus*.

II. EVOLUTION OF THE INSECT HEAD

When we examine an insect embryo in an early stage of development (fig. 5 A, B) we see that its head consists of an enlargement (*Prc*) of the anterior end of the elongate body, formed of lateral

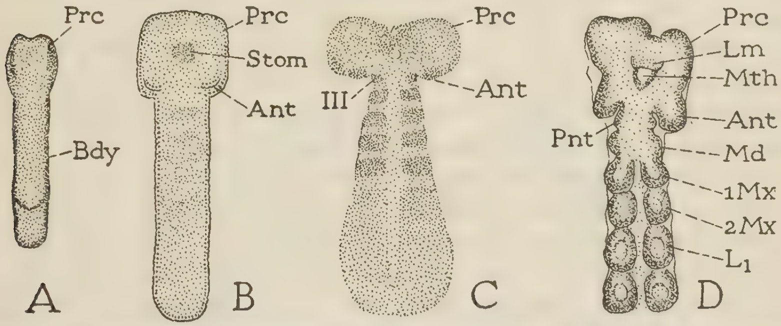

FIGURE 5.—Series of insect embryos showing development of the procephalic lobes (*Prc*) and head appendages

A, young embryo of a roach (from Riley, 1904). B, older embryo of same, showing enlarged procephalic lobes, with mouth (*Stom*) and antennae (*Ant*) forming on under surface (from Riley, 1904). C, young embryo of *Lepisma*, showing third head segment (*III*) united with protocephalon (from Heymons, 1897). D, embryo of roach in later stage, showing rudiments of postantennal appendages (*Pnt*), and developing gnathal appendages (*Md*, *1Mx*, *2Mx*) on region behind procephalic lobes (from Riley, 1904).

swellings of the germ band, which embryologists call the *cephalic lobes*. On this embryonic head there are later formed the eyes, the antennae (D, *Ant*), the mouth (*Mth*), and a median lobe before the mouth, which is the rudiment of the labrum (*Lm*). In addition to these parts, however, there has been observed in the embryo of a walking-stick insect (Wiesmann, 1926), and also of a centipede (Heymons, 1901), very small rudiments of a pair of preantennal appendages; and there are commonly present in insect embryos rudiments of a pair of postantennal appendages, though the latter are sometimes situated not definitely on the region of the cephalic lobes, but very close behind them (D, *Pnt*).

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The cephalic lobes of the insect embryo do not in themselves show any sign of division into segments, but the presence of three pairs of appendages on them, or closely associated with them, is taken as evidence that the cephalic region includes three primitive segmental areas, and this assumption appears to be confirmed by the fact that the head region of the embryo contains three successive pairs of cavities (coelomic sacs) in the mesoderm. The assumed procephalic segments, or primitive head somites, then, may be distinguished according to their appendages in insects as the preantennal, the antennal, and the postantennal head segments; though, according to the names given to the head appendages in Crustacea, they are called the preantennular, antennular, and antennal segments, respectively.

In addition to the segmental areas in the procephalic region of the embryo, there is still the large, anterior apical area on which the labral rudiment is situated. This area, which some embryologists call the *acron*, would appear to be the equivalent of the prostomium of an annelid worm (fig. 1, *Pst*), since it is preoral in position. The acron has no true appendages, unless the labrum represents a pair of united appendages, but, according to some investigators, the compound eyes are developed upon it. Generally it has been supposed that the compound eyes belong to the first true segment, and since the eyes are borne on movable stalks in some Crustacea, it has often been thought that the eye stalks are the appendages of the first head segment. If it is true, however, that there are appendage rudiments on the first segment having nothing to do with the compound eyes, the appendage idea of the eye stalks must be discarded. In the light of recent comparative studies on the internal structure of the brain and optic lobes of annelids and arthropods (see Hanström, 1928), it now appears certain that the compound eyes, the ocelli, and most of the forebrain of the arthropods must be assigned to the prostomium. The preantennal appendage rudiments have at most an evanescent embryonic existence; the antennal rudiments become the antennae of the adult insect, or the first antennae (antennules) of Crustacea; the postantennal rudiments are also suppressed in insects, though perhaps they persist in certain species as small lobes of the mature head, but in Crustacea they become the large second antennae of the adult (fig. 16 B, *2Ant*).

If we attempt, now, to translate the facts of the embryonic development of the head into a phylogenetic concept, we must believe that the ancestors of the insects at some time in their history had a head corresponding with the region of the cephalic lobes in the embryos of modern insects. Since we have no record of earlier stages in the evolution of the arthropod head, though presumably such stages

existed, we may call the phylogenetic equivalent of the embryonic head the *protocephalon.* The protocephalon is preserved as the entire adult head in many Crustacea, as in the phyllopods (fig. 2 A, *Prc*) and in the shrimps, crabs, and lobsters (fig. 16 A, *Prc*). In insects, chilopods, diplopods, and some crustaceans it forms only the procephalic part of the definitive head.

Looking again at an insect embryo in a late protocephalic stage of its head development (fig. 5 D), we observe that the body segments immediately following the cephalic lobes have each a pair of well-developed appendage rudiments (*Md*, *1Mx*, *2Mx*). These appendages do not differ at first from the leg rudiments (*L*), but they do not keep up in growth with the legs, and in some insects the region of the legs, or *thorax* (fig. 6, *Th*), is soon differentiated from a region of three segments (*Gn*) between the thorax and the protocephalon (*Prc*). The appendages of these segments (*Md*, *1Mx*, *2Mx*) become the mandibles and the two pairs of maxillae of the adult insect. The part of the embryonic body bearing them is termed, therefore, the *gnathal region.* Before the insect embryo hatches, the gnathal segments are united with the cephalic lobes, and all the parts thus brought together are consolidated in the *definitive head.* The intersegmental lines, with the possible exception of the line between the two maxillary segments, are completely obliterated, while the surface of the mature head capsule becomes secondarily subdivided by the lines of cuticular inflections forming internal ridges which strengthen its walls. The gnathal appendages constitute the principal external feeding organs of the insect. Being crowded forward on the ventral side of the head, the first pair, or mandibles, come to lie at the sides of the mouth, and are transformed into jawlike organs having a biting and chewing function.

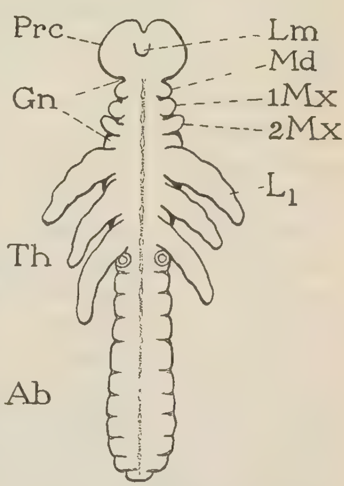

FIGURE 6.—An insect embryo showing distinct differentiation of the body into four parts, protocephalon (*Prc*), gnathal region (*Gn*), thorax (*Th*), and abdomen (*Ab*). Embryo of *Ranatra fusca* (from Hussey, 1926)

There is no doubt, from the embryological evidence, that the insect head has been formed from the union of two regions of the primitive trunk, the first region, bearing the eyes, the labrum, the mouth, and the antennae, being the *procephalon*, the second, bearing the gnathopods and the hypopharynx, the *gnathocephalon.* The idea

that the procephalon is composed of the prostomium and three postoral somites, and that the gnathocephalon contains three somites is currently accepted by most entomologists as approximately representing the facts, but there are several reasons for questioning if the evidence of segmentation in each of the two parts of the head has been rightly interpreted.

A comparative study of the brain in the Arthropoda and Annelida leads to quite a different concept of the head segmentation than that derived from a study of the appendages. According to Holmgren (1916) and Hanström (1928), the three divisions of the arthropod brain, ordinarily assumed to correspond with three segments in the procephalic head region, represent only two primary nerve centers instead of three. The first of the two primary parts, these writers claim, represents the prostomial archicerebrum of the Annelida, and is secondarily differentiated into the definitive forebrain and midbrain (protocerebrum and deutocerebrum) of the Arthropoda; the second primary part (tritocerebrum) is formed of the first pair of ventral, postoral ganglia, which have united with the primitive preoral ganglion, but retain their ventral commissure.

As a corollary to this theory we should have to believe that the cephalic lobes of the arthropod embryo (fig. 5, *Prc*) represent the annelid prostomium, with the first (tritocerebral) segment generally more or less united with it. The preantennal and antennal appendages, and the eye stalks of Crustacea then become organs equivalent to the annelid prostomial tentacles (fig. 1 B, *Tl*), while the second antennae are the first true segmental appendages. There is much in the structure of the brain and in the innervation of the head to support this theory. On the other hand, the preantennal and antennal rudiments of the embryo appear to be true ventral, postoral appendages homologous with the second antennae and the mouth appendages, and the presence of three pairs of coelomic sacs in the procephalic region indicates that there are here three true segments in addition to the prostomium.

Another problem in the theoretical morphology of the insect head is one that concerns the number of somites that enter into the composition of the gnathal region of the definitive head capsule, and the homologies of the mouth-part appendages of insects with those of the Crustacea.

The insect mouth parts, as we have seen, include a median, tongue-like lobe of the ventral wall of the head, lying between the mandibles and the maxillae, known as the hypopharynx. In some insects the hypopharynx has a pair of lateral lobes, and in such cases the median part of the organ is distinguished as the *lingua* (fig. 7 A, *Lin*), and the lateral lobes as the superlinguae (*Slin*). The superlinguae are

said to be developed in the embryos of more primitive insects separate from the lingua and somewhat anterior to it. They are, therefore, regarded by some writers (Folsom, 1900, Denis, 1928, Hansen, 1930) as a pair of true segmental appendages in the gnathal region of the head. In the apterygote family Machilidae the superlinguae have a structure suggestive of their being reduced appendicular organs (fig. 7 B), each having two terminal lobes (*a*, *b*), and near its base a small, palpuslike process (*c*).

A hypopharyngeal structure similar to that of the apterygote insects occurs in some of the Crustacea (fig. 7 C), but the lateral lobes of the crustacean hypopharynx are called *paragnatha* (*Pgn*), and the median, lingual lobe is not always present (fig. 18 B). Because of the similarity between the superlinguae and the paragnatha many students of arthropods, following Crampton (1921),

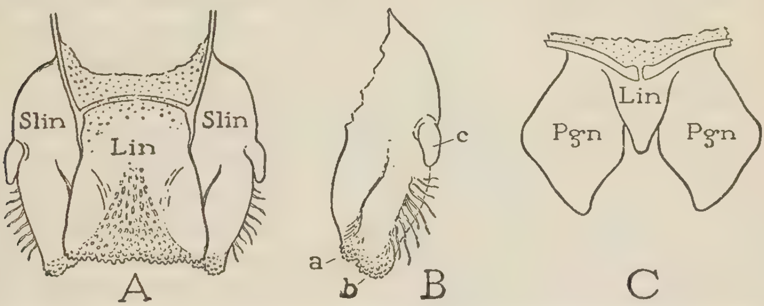

FIGURE 7.—Showing similarity in structure of the hypopharynx between certain insects and some crustaceans

A, hypopharynx of an apterygote insect, *Nesomachilis*, composed of a median lingua (*Lin*) and lateral superlinguae (*Slin*), posterior view. B, left superlingua of same, anterior view. C, Hypopharynx of an isopod crustacean, formed of median lingua and lateral paragnatha (*Pgn*), posterior view.

have regarded the two organs as homologous structures. Others, however, including Folsom (1900), Henriksen (1929), Hansen (1930), and Tuxen (1931), believe that the superlinguae are the first maxillae (maxillulae) of Crustacea, and that the paragnatha are not appendicular organs. Folsom (1900) claimed to have found in a collembolan insect that the superlinguae are innervated from a special center in the suboesophageal ganglion of the head, as does also Denis (1928), but the two investigators do not agree as to the position of the nerve center. On the other hand, Philiptschenko (1912) denies the existence of a superlingual nerve center, and Hoffman (1911) asserts that the superlinguae are mere secondary outgrowths of the head wall at the inner angles of the mandibles. The idea that the paragnatha of the Crustacea are segmental appendages appears to have no champion, though Denis (1928) recognizes

it as a possibility. The paragnatha are said to be innervated by branches of the mandibular nerves.

If the superlinguae are true appendages, the gnathal region of the insect head must contain four segments instead of three, as it does in some Crustacea. Then, if the paragnatha are *not* true appendages, the insect superlinguae must represent the first maxillae (maxillulae) of Crustacea, the maxillae the second maxillae (maxillae), and the labial appendages the first pair of crustacean maxillipeds.

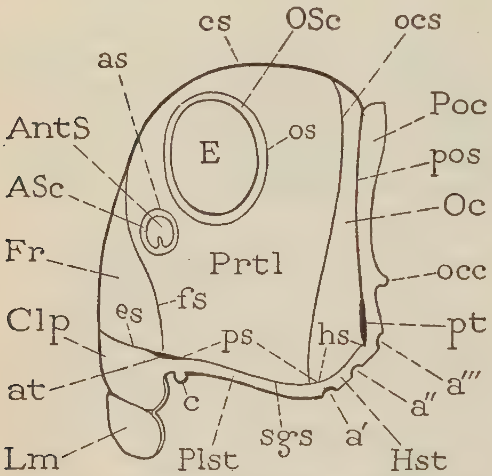

Figure 8.—Diagram of the principal sutures and areas of an insect's cranium

a', posterior articulation of mandible; *a''*, articulation of maxilla; *a'''*, articulation of labium; *AntS*, antennal socket; *as*, antennal suture; *ASc*, antennal sclerite; *at*, anterior tentorial pit; *c*, anterior articulation of mandible; *Clp*, clypeus; *cs*, coronal suture; *E*, compound eye; *es*, epistomal suture; *Fr*, frons; *fs*, frontal suture; *hs*, hypostomal suture; *Hst*, hypostoma; *Lm*, labrum; *Oc*, occipital arch; *occ*, occipital condyle; *ocs*, occipital suture; *os*, ocular suture; *OSc*, ocular sclerite; *Plst*, pleurostoma; *Poc*, postocciput; *pos*, postoccipital suture; *Prtl*, parietal; *ps*, pleurostomal suture; *pt*, posterior tentorial pit; *sgs*, subgenal suture.

The dispute as to the nature of the superlinguae, the number of segments in the gnathal region of the insect head, and the homology between the mouth parts of insects and crustaceans is now over 30 years of age and appears to be destined to a long life. The best advice that can be offered to the student is that there is much to be said on both sides, which has already been said, and that some conclusive evidence would be more convincing. The subject of the segmentation of the arthropod head and the homologies of the head appendages between insects and crustaceans has been reviewed recently by Denis (1928), Henriksen (1929), Imms (1931), and Tuxen (1931).

III. STRUCTURE OF THE MATURE HEAD CAPSULE

Whatever may be the exact facts concerning the evolutionary history of the cephalic region of insects, the component elements of the mature cranial capsule are so closely consolidated in modern insects that entomologists can find little evidence of the lines that formerly demarked the constituent parts or segments. Only one constant suture of the insect head appears to have an intersegmental

value. This suture is a groove lying very close to the posterior rim of the cranium (fig. 8, *pos*), where it forms an inflection, or internal ridge, around the dorsal and lateral aspects of the foramen magnum. Since this suture lies behind the region of the head commonly called the occiput (*Oc*), we may term it the *postoccipital suture* (*pos*). The narrow marginal rim of the cranium (*Poc*) set off at the base of the neck (fig. 12 A, *Cv*) by the postoccipital suture may be designated, therefore, the *postocciput* (*Poc*). The postocciput is well developed in the cricket (fig. 9 B, *Poc*), and its internal inflection, the *postoccipital ridge* (*PoR*), is particularly large.

One reason for regarding the postoccipital suture as an intersegmental groove is the fact that the dorsal head muscles from the thorax are always attached on its internal ridge, just as the other longitudinal muscles of the body are attached on intersegmental ridges of the thoracic and abdominal skeletal plates. We might, therefore, regard the postoccipital suture as the true separation between the head and the prothorax, the neck being thus included in the latter; but evidence derived from embryonic development (Riley, 1904, Eastham, 1930) suggests, rather, that the postoccipital suture is the line of separation between the two maxillary segments of the head. The usual attachment of the maxillae on the head (figs. 8, a'', 12 A, *Mx*) before the lower ends of the suture, and that of the labium, behind the suture (figs. 8, a''', 12 A, *Lb*) is in accord with this theory. If the second view is correct, then the postocciput of the cranium is a sclerotic remnant of the dorsal arch of the labial segment. Dorsal muscles of the labium, in this case, should arise on the postocciput, but since the labium ordinarily has no dorsal muscles, a crucial point in the evidence is missing. The region of the neck may be supposed to include a posterior membranous part of the labial segment, and the anterior part of the first thoracic segment.

We have already observed that in the Crustacea the dorsal plates of the two maxillary segments are always intimately fused, as in *Eubranchipus* and *Anaspides* (figs. 2 A, 16, *V* + *VI*), in which respect the crustaceans appear to differ from the insects. In both of these crustacean forms, however, the mandibular segment is separated from the maxillary segment by a distinct suture (*y*), which suture is possibly represented in the thysanuran insect *Machilis* (fig. 2 B) by the suture on the back part of the head (*y*) that ends ventrally between the bases of the mandibles and the first maxillae.

The sutures of the head.—Aside from the postoccipital suture, the surface of the cranium is usually marked by other impressed lines, collectively termed "sutures," which are characteristic features of the head, though they all appear to be of secondary formation. The so-called sutures of this type have no significance in

themselves—most of them are merely the lines of inflections forming internal skeletal ridges which strengthen the cranial capsule, but the sutures divide the head walls into areas that are convenient units for descriptive purposes. The cranial sutures are not always present, but those described in the following paragraphs recur so frequently that they are regarded as typical features of the insect head.

On the top of the cranium there is in many insects a median *coronal suture* (figs. 8, 9 A, 10, *cs*). Anteriorly the suture forks into two *frontal sutures*, which, when complete, diverge downward on the facial region (fig. 8, *fs*) *between* the bases of the antennae, to the neighborhood of the anterior mandibular articulations (*c*).

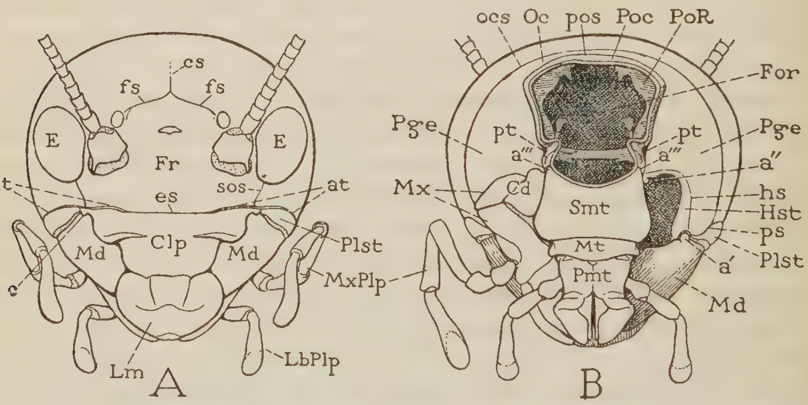

FIGURE 9.—Head of a cricket, *Gryllus assimilis*

A, anterior view; B, posterior view; *a'*, *a''*, *a'''*, primary articulations of mandible, maxilla, and labium; *at*, anterior tentorial pit; *c*, secondary anterior articulation of mandible; *Cd*, cardo; *Clp*, clypeus; *cs*, coronal suture; *E*, compound eye; *es*, epistomal suture; *For*, foramen magnum; *Fr*, frons; *fs*, frontal suture; *hs*, hypostomal suture; *Hst*, hypostoma; *Lm*, labrum; *LbPlp*, labial palpus; *Md*, mandible; *Mt*, mentum; *Mx*, maxilla; *MxPlp*, maxillary palpus; *Oc*, occiput; *ocs*, occipital suture; *Pge*, postgena; *Plst*, pleurostoma; *Pmt*, prementum; *Poc*, postocciput; *PoR*, postoccipital ridge; *pos*, postoccipital suture; *ps*, pleurostomal suture; *pt*, posterior tentorial pit; *Smt*, submentum; *sos*, subocular suture.

In the cricket (fig. 9 A) the coronal suture is but weakly marked, and the frontal sutures end at the lateral ocelli. In the cockroach also the frontal sutures are incomplete (fig. 10). Both the coronal and the frontal sutures are often entirely suppressed, and in some cases secondary sutures branch from the coronal suture and diverge laterad of the antennal bases. During molting the cuticula of the head usually splits along the coronal suture, and may extend down one or both of the frontal sutures; but there are many exceptions to this rule, as in caterpillars, where, in all but the last molt, the head capsule breaks off at the neck.

Near the lower margins of the lateral walls of the cranium there is usually on each side a horizontal *subgenal suture* (fig. 8, *sgs*),

which when fully developed extends forward from the posterior tentorial pit (*pt*) in the lower end of the postoccipital suture to a point just above the anterior articulation of the mandible (*c*). The part of the subgenal suture between the two mandibular articulations (*c*, *a′*) is sometimes distinguished as the *pleurostomal suture* (*ps*), and the part behind the mandible as the *hypostomal suture* (*hs*). Very commonly the anterior ends of the subgenal sutures are connected across the face by an *epistomal suture* (*es*). The subgenal sutures are well developed in both the cricket and the cockroach (figs. 9, 10), but in the roach the epistomal suture is absent.

The anterior tentorial pits of pterygote insects (fig. 8 *at*) are always located somewhere in the pleurostomal or epistomal sutures, but their position in the sutures is subject to much variation in different insects. In the cricket (fig. 9 A) each " pit " (*at*) is a long slit occupying almost the entire length of the pleurostomal suture and extending a considerable distance into the epistomal suture. More commonly the pits lie entirely within the epistomal suture, and are often carried upward on the face with the dorsal arching of the suture common in many insects.

Extending across the back of the cranium there is in some insects an *occipital suture* (fig. 8, *ocs*), which may reach downward on the lateral head walls to the subgenal sutures. An occipital suture is well developed in most Orthoptera, as in the cricket (fig. 9 B, *ocs*), along the line where the dorsal and lateral walls of the cranium are inflected into the posterior wall. The *postoccipital suture* (*Pos*) has already been described. It is always present, but if the postocciput (*Poc*) is absent, the postoccipital suture becomes merely a groove marking the line of attachment of the neck membrane to the posterior rim of the head.

Still other sutures frequently occur in the head wall, but they are less constant than those described above. Often an *ocular suture* (fig. 8, *os*) surrounds the compound eye; and generally the antennal socket is encircled by an *antennal suture* (*as*), the internal ridge of which strengthens the rim of the socket. In the cricket a *subocular suture* (fig. 9, A, *sos*) extends from the compound eye to the subgenal suture, and in the roach a *subantennal suture* (fig. 10, *sas*) extends from the antennal socket to the subgenal suture. These sutures are sometimes called " fronto-genal " sutures, but it is doubtful if the part of the head wall immediately before them belongs to the area of the true frons (fig. 8, *Fr*).

The areas of the head.—The head areas are merely the spaces between the head sutures. They are often called " sclerites," but they must not be thought of as plates united along the sutures; they are

simply the result of the secondary division of the cranial wall by the linear inflections, or "sutures," forming the internal ridges.

Above the line of the subgenal and epistomal sutures there are five principal head areas (fig. 8). On the face between the frontal sutures is the median, triangular *frons* (*Fr*). The side walls of the head between the frontal and occipital sutures, separated above by the coronal suture, are the *parietals* (*Prtl*), inclosing the compound eyes and the antennal sockets. The top of the two parietals is known as the vertex, and the parts below the eyes are the *genae*. On the back of the head, between the occipital and postoccipital sutures, is the occiput, or *occipital arch* (*Oc*). The dorsal part of the arch is usually termed the *occiput* in a more restricted sense (fig. 9 B, *Oc*), and the lateral parts the *postgenae* (*Pge*). In the grasshopper *Melanoplus* a suture on each side separates the dorsal occipital area from the lateral postgenal areas. The posterior rim of the cranium behind the postoccipital suture is the *postocciput* (fig. 8, *Poc*). The postocciput bears the *occipital condyles* (*occ*) by which the anterior neck plates articulate with the head (fig. 12 A, *cvpl*). In most insects the postocciput is a narrow sclerotic flange to which the neck membrane is attached (fig. 9 B, *Poc*); but it is often much reduced, except for remnants bearing the occipital condyles (fig. 13), and it is sometimes completely obliterated.

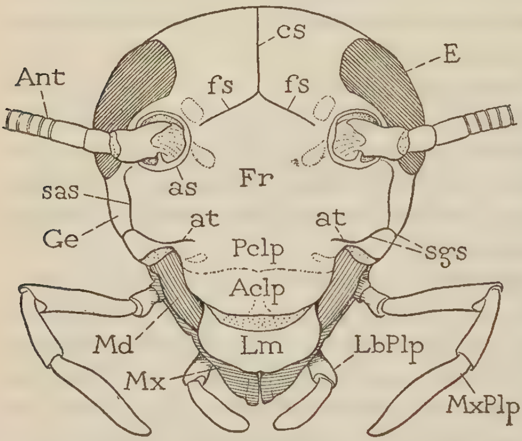

FIGURE 10.—Facial view of the head of a roach, *Blatta orientalis*

Aclp, anteclypeus; *Ant*, antenna; *as*, antennal suture; *at*, anterior tentorial pit; *cs*, coronal suture; *E*, compound eye; *Fr*, frons; *fs*, frontal suture; *Ge*, gena; *LbPlp*, labial palpus; *Lm*, labrum; *Md*, mandible; *Mx*, maxilla; *MxPlp*, maxillary palpus; *Pclp*, postclypeus; *sas*, substantennal suture; *sgs*, subgenal suture.

Below the line of the subgenal and epistomal sutures (fig. 8, *sgs*, *es*) there is on each side of the head a narrow marginal band above the bases of the mouth parts (fig. 12 A), and on the front of the head a broad area, known as the *clypeus* (figs. 8, 12 A, *Clp*), which supports the *labrum* (*Lm*). Just as the parts of the subgenal suture lying before and behind the posterior mandibular articulation (fig. 8, *a′*) are distinguished for descriptive purposes as the pleurostomal suture (*ps*) and the hypostomal suture (*hs*), so the corre-

sponding parts of the subgenal strip may be distinguished as the *pleurostoma* (*Plst*) and the *hypostoma* (*Hst*). In conformity with this nomenclature, the upper part of the clypeus is sometimes called the *epistoma*, though, when the clypeus is divided, its parts are more commonly termed the *anteclypeus* and the *postclypeus.* The pleurostoma is usually a small but distinct subgenal area above the mandible (fig. 9 A, *Plst*); the hypostoma is typically a narrow marginal band of the postgenal area of the cranium (figs. 9 B, 13, *Hst*), but in some insects, as in lepidopterous larvae and in adult Hymenoptera and Diptera, the hypostomata are greatly enlarged and extended medially on the ventral wall of the head, where, in the higher Hymenoptera and Diptera, they are united into a continuous hypostomal bridge. The epistomal-pleurostomal-hypostomal marginal area of the cranium constitutes the *peristome.*

The internal skeleton of the head.—The ventral edges of the cranium are usually braced by an internal skeletal structure known

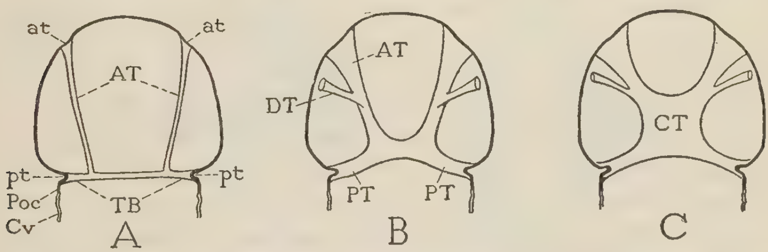

FIGURE 11.—Diagrams showing progressive modifications of the tentorium from the generalized condition at A, through B, to specialized structure at C

At, anterior arm; *at*, anterior tentorial pit; *CT*, corpotentorium; *Cv*, neck; *DT*, dorsal arms; *PT*, posterior arms; *pt*, posterior tentorial pits; *Poc*, postocciput; *TB*, posterior tentorial bar.

as the *tentorium*, which, in the absence of a substantial floor to the cranium, gives attachment to the ventral muscles of the mouth appendages. The tentorium, in its typical form (fig. 11 A), consists of a transverse posterior *tentorial bar* (*TB*) extending through the back part of the head between the posterior tentorial pits (*pt*, *pt*), and of two longitudinal *anterior tentorial arms* (*At*, *At*), arising at the anterior tentorial pits (*at*, *at*) and uniting posteriorly with the transverse bar near its lateral extremities. The whole structure is formed by four cuticular invaginations, the roots of which are marked by the external pits. In many insects the posterior ends of the anterior arms are approximated (fig. 11 B), and they may be united in a broad median plate (C). By such modifications the tentorium in appearance often departs radically from its more primitive structure. The central plate is called the *corpotentorium* (C, *CT*), and the lateral parts of the transverse bar become the *posterior tentorial arms* (B, C, *PT*, *PT*). Branches from the ante-

rior arms commonly extend upward to the facial wall of the head and attach to the latter in the neighborhood of the antennal bases. These branches constitute the *dorsal tentorial arms* (B, *DT*).

The posterior tentorial bar always forms a bridge between the lower ends of the postoccipital suture; it never departs from this position. The roots of the anterior arms vary in position, though in pterygote insects they always lie somewhere in the pleurostomal or epistomal sutures. In most of the apterygote insects, however, the anterior tentorial arms arise from the *ventral* wall of the head near the base of the hypopharynx. In their origin, therefore, the anterior arms are sternal apophyses, on which the ventral muscles of the mouth appendages take their origin. It can not be explained exactly how the primitively ventral arms have acquired lateral or

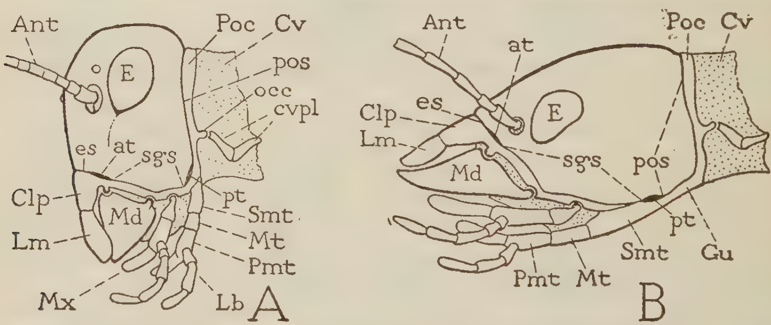

Figure 12.—Diagrams showing hypognathous (A) and prognathous (B) types of head structure

Ant, antenna; ***at***, anterior tentorial pit; ***Clp***, clypeus; ***Cv***, neck; ***cvpl***, cervical sclerites; ***E***, compound eye; ***es***, epistomal suture; ***Gu***, gula; ***Lb***, labium; ***Lm***, labrum; ***Md***, mandible; ***Mt***, mentum; ***Mx***, maxilla; ***occ***, occipital condyle; ***Pmt***, prementum; ***Poc***, postocciput; ***pos***, postoccipital suture; ***pt***, posterior tentorial pit; ***sgs***, subgenal suture.

facial attachments on the walls of the cranium in pterygote insects, but the altered position of their bases has come about probably either by a lateral migration before the mandibles, or by the establishment of secondary connections with the cranial walls accompanied by a loss of the primary sternal connections with the floor of the head.

Modifications in the form of the head.—The relative size or the shape of an insect's head is no index of the brain power of the insect; on the contrary it usually expresses the strength of the jaws, or some other quality connected with feeding. In the biting and chewing insects the parietal areas of the cranium are often enlarged to accommodate the jaw muscles; in sucking insects the facial area may be amplified to provide space for the muscles of the suction pump.

With most of the more generalized insects the frontal aspect of the head is directed forward, and the mouth appendages hang downward from the subgenal margin. A head having this position (fig. 12 A) is said to be of the *hypognathous type.* The hypognathous type of head undoubtedly preserves the primitive relation of the cranium with the body, because the mouth appendages are modified legs, and in the pendent position they correspond with the legs, and retain the embryonic position of the primitive appendages.

There are many insects, however, in which the frontal aspect of the head is turned upward, and the mouth appendages are directed forward. When the cranium has this relation to the body (fig. 12 B), the head is of the *prognathous type.* The prognathous position of the head is unquestionably a secondary one, as is shown in the structure of the cranium. The back of the head usually maintains the primitive relation with the neck (B, *Cv*), but the forward position of the jaws has involved a lengthening of the ventral head wall and the basal region of the labium (*Smt*). In many prognathous insects, particularly in Coleoptera, the posterior tentorial pits (*pt*) have been drawn forward on the ventral head wall, and the lower ends of the postoccipital suture (*pos*), which terminate in the pits, have been correspondingly lengthened by a forward extension on the ventral side of the cranium. The suture continued anteriorly from each tentorial pit is the subgenal suture (*sgs*), which ends at the anterior tentorial pit (*at*) in the usual manner.

The position or structure of all the mouth appendages is more or less affected by the transformation from the hypognathous to a prognathous condition. The hinge line of the mandible (fig. 12 B, *Md*) comes to approach a vertical position. The maxillae are carried forward on the ventral side of the head, since they retain the normal articulation with the hypostomal margins of the head immediately behind the mandibles. It is the labium that is most affected by the change. Its basal region becomes greatly elongate between the ventral extensions of the postoccipital suture and the posterior, or hypostomal, parts of the subgenal sutures, and appears to be a plate of the ventral wall of the head. The part of the labium posterior to the tentorial pits (*pt*) is now called the *gula* (*Gu*).

A concrete example of the structure of a prognathous head in the Coleoptera is well shown by the head of a blister beetle (fig. 13). The postoccipital rim of the cranium is here almost obliterated, except laterally where it bears the large occipital condyles (*occ*). The ventral parts of the postoccipital sutures (*pos*), however, are extended forward on the ventral side of the head to the posterior tentorial pits (*pt*, *pt*), and they separate the enlarged gular area of the labium (*Gu*) from the postgenal regions of the cranial wall.

The parts of the postgenal sutures lying at the sides of the gula are distinguished as the *gular sutures.* The sutures extending forward from the tentorial pits are the hypostomal sutures (*hs*), which diverge anteriorly to the lower margins of the compound eyes (E), and set off distinct hypostomal areas (*Hst*) behind the bases of the maxillae (*Mx*).

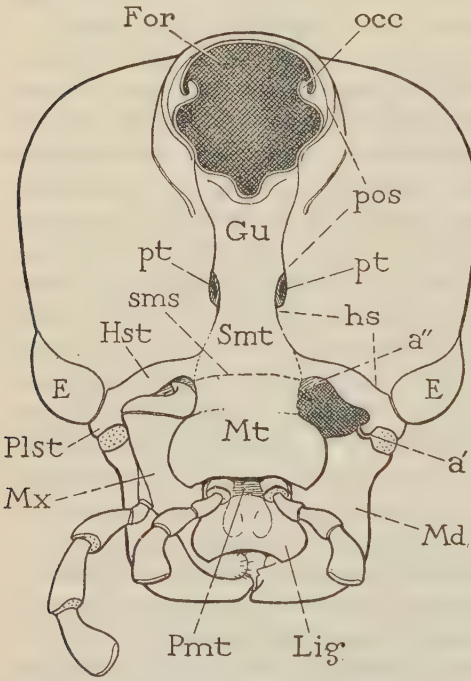

FIGURE 13.—Ventral surface of the head of a blister beetle, *Epicauta marginata,* illustrating the development of the gula (*Gu*) in an elongate prognathous head. Posterior tentorial pits (*pt, pt*) transposed forward on ventral side of head; lower ends of postoccipital suture (*pos*) correspondingly elongate at sides of gular region (*Gu*) added to submentum (*Smt*)

IV. GENERAL STRUCTURE OF ARTHROPOD APPENDAGES

When we come to study the appendicular organs of the head associated with the mouth, by which insects obtain their food, we must bear in mind that these structures are legs modified for purposes of feeding. The primitive feeding legs, or *gnathopods*, were not necessarily like the thoracic legs of insects, which are specialized locomotory organs, but it is probable that they resembled the locomotory appendages, or pereiopods, of modern Arthropoda more closely than the members of any other specialized group of appendages.

An appendicular organ having a locomotor function must be movable on the body. Movement implies the presence of muscles so attached on the base of the appendage that the muscles and the appendage together will constitute a definite mechanism capable of a specific kind of action. Since we do not have any examples of really primitive arthropods, and could not study the muscular system if we had a fossil specimen of one, we can only construct an imaginary picture of the mechanism of a primitive arthropod appendage from theoretical considerations. But, inasmuch as unknown truth in actuality must take some specific form, a theory has at least a chance of being right. There can be little question, now, that a primitive locomotory appendage turned forward

and rearward on a vertical or approximately vertical line of flection between its base and the side or ventrolateral aspect of the body segment to which it was attached. It must have had, therefore, *promotor* and *remotor* muscles; and, if so, it is reasonable to assume that these muscles took their origins on the dorsum and on the venter of the segment supporting the appendage. We have thus a very simple picture of the mechanism of a primitive limb (fig. 14, *Appd*), or locomotor appendage capable of turning forward and rearward on a dorsoventral axis (*a–b*) with the body by *dorsal promotor* and *remotor* muscles (*I*, *J*), and *ventral promotor* and *remotor* muscles (*K*, *L*). A concrete example of this type of limb musculature may be found in the annelid worms provided with parapodia, and likewise in the worm-like peripatids (Onychophora). From this begin-

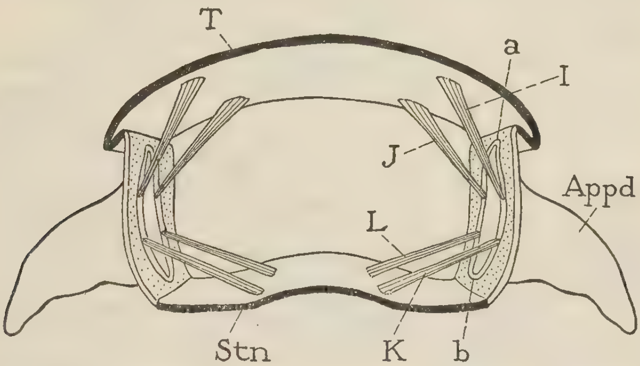

Figure 14.—Diagram of the musculature of a primitive segmental appendage

a-b, axis of basal movement of appendage on body; *Appd*, appendage; *I*, dorsal promotor muscle; *J*, dorsal remotor; *K*, ventral promotor; *L*, ventral remotor; *Stn*, sternum; *T*, tergum.

ning we may follow in our imagination the evolutionary course of the appendage into a more efficient organ of locomotion with a more diversified structure and mechanism.

An appendage movable only at its base, such as the annelid parapodia, can be at best only a crude organ of progression. The arthropods owe their superiority over the worms to the greater efficiency of their appendages.

The first step in the development of the appendages in the primitive Arthropoda, it would seem, must have consisted of a functional division of each organ into a *basis* (fig. 15 A, *LB*), and a distal shaft, or *telopodite* (*Tlpd*). The appendage as a whole having already a basal movement in a horizontal direction, the telopodite must naturally have moved in a vertical plane on the basis, and it then must have had *levator* and *depressor* muscles (*O*, *Q*) arising in the basis. The baso-telopodite joint (*ct*) can be identified apparently

in the limbs of all present-day arthropods by the uniformity of its movement and musculature.

The next step in line with greater mechanical improvement in the appendage produced a point of flexure near the middle of the telopodite (fig. 15 B, *ft*), enabling the distal part of the latter to be more effectively brought down against the support. Hence, in all fully developed arthropod limbs there is a "knee" joint (C, *ft*) in the telopodite with a principal downward movement of the part beyond the knee.

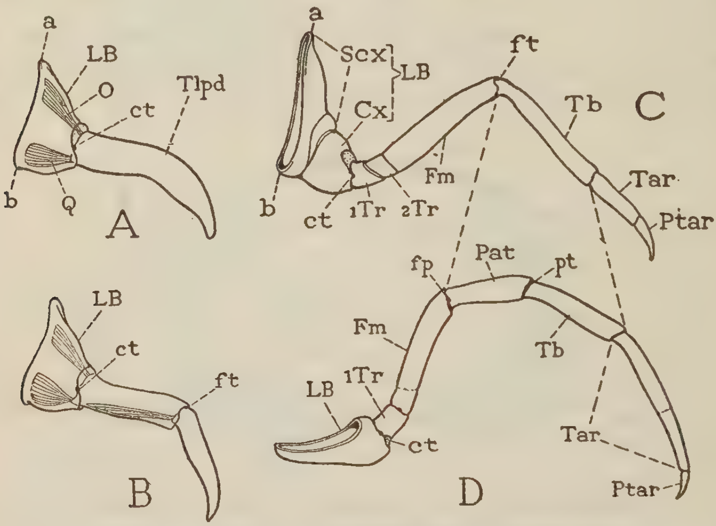

Figure 15.—Diagrams of segmentation of arthropod legs

A, primary division into basis (*LB*) and telopodite (*Tlpd*) at coxo-trochanteral joint (*ct*). B, division of telopodite at knee joint (*ft*). C, complete segmentation of an insect's leg. D, a typical arachnid leg. *a–b*, axis of limb basis on body; *ct*, coxo-trochanteral joint; *Cx*, coxa; *Fm*, femur; *ft*, femoro-tibial joint; *LB*, limb basis; *O*, levator muscle of telopodite; *Pat*, patella; *pt*, patello-tibial joint; *Ptar*, praetarsus; *Q*, depressor muscle of telopodite; *Scx*, subcoxa; *Tar*, tarsus; *Tb*, tibia; *Tlpd*, telopodite; *1Tr*, first trochanter; *2Tr*, second trochanter.

We may thus conceive of the early arthropods as being centipede-like creatures with a series of legs on each side of the body, the legs all jointed in the same way, and moving by a uniform kind of motion. The appendages all turned forward and rearward on the body; they all turned upward along the line of the baso-telopodite joints; and the distal parts uniformly bent downward at the knee joints. Subsequently the major parts of the telopodite of each limb have been still further segmented (fig. 15 C, D), and in some arthropods the basis, too, appears to have been subdivided (C, *LB*).

If we define a limb segment (*podite*, or *podomere*) as any movable section of the appendage individually provided with muscles, it is found that in the Crustacea, Myriapoda, and Hexapoda each fully developed appendage has six segments in the telopodite. There are two sets of names applied to the limb segments, one set generally used by entomologists, the other by carcinologists, as follows: *First trochanter*, or *basipodite*, (fig. 15 C, *1Tr*); *second trochanter*, *praefemur*, or *ischiopodite* (*2Tr*); *femur*, or *meropodite* (*Fm*); *tibia*, or *carpopodite* (*Tb*); *tarsus*, or *propodite* (*Tar*); and *praetarsus*, *claw segment* (*Krallenglied*), or *dactylopodite* (*Ptar*). In the legs of most insects the two trochanters are fused into a single segment, and in some Hymenoptera a subsegment resembling a trochanter is constricted from the base of the femur. The tarsus is often secondarily broken up into two or more subsegments, but the tarsal subsegments are never provided with muscles. A different type of segmentation occurs in some of the appendages of most of the Chelicerata (fig. 15 D), in which there are two segments intervening between the femur and the tarsus, the first called the *patella* (*Pat*), the second the tibia (*Tb*).

The limb basis becomes functionally the most important part of a gnathal appendage. In the Arachnida and in most of the Crustacea the basis is a single segment, known as the *coxopodite* (fig. 15 D, *LB*). In the legs of Chilopoda and Hexapoda, however, the basis appears to include two segments ,the *subcoxa* and the *coxa* (C, *Scx*, *Cx*), the first of which becomes an immovable support for the rest of the limb incorporated into the body wall. The primitive hinge between the subcoxa and the coxa was probably vertical, since it replaces the primary articulation of the limb with the body; but in the legs of many insects it has undergone various modifications. The basis of the mouth appendages may also be subdivided into a proximal and a distal part, the so-called *cardo* and *stipes* (fig. 19, *Cd*, *St*), but it is questionable if these parts are equivalent to the subcoxa and coxa of a leg.

Finally, we should observe that in most of the arthropod groups some of the appendages may be provided with accessory lobes borne by the limb segments, and often furnished with muscles arising in the segments to which the lobes are attached. Lobes on the outer margin of an appendage are distinguished as *exites*, lobes on the inner margin as *endites*. In the Crustacea an exite of the first trochanter (ischiopodite) often forms a large branch of the appendage, known as the *exopodite*. Endite lobes are particularly developed on the gnathal appendages, where they have special functions in connection with feeding.

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V. MOUTH PARTS OF A CRUSTACEAN

It was recommended in the introductory section of this paper that entomologists should not confine their investigations to insects, since valuable information bearing on the structural evolution of insects may often be obtained from members of related groups of animals. Specialization is a necessity, but it should not be carried to the extent it is practised in some institutions, where it is regarded as a breach of professional etiquette for a specialist in one group to acquire any first-hand information in the field of another specialist.

In sleuthing out information by the method of examining the relatives of an animal under investigation it is always important to be able to pick out a communicative subject. On the island of Tasmania there live two little fresh-water crustaceans, named *Anaspides* and *Paranaspides*. An interesting account of the life and habits of these two isolated creatures is given by Miss S. M. Manton (1930). *Paranaspides* inhabits the Great Lake of Tasmania situated at a height of 3,700 feet. *Anaspides* lives on Mount Wellington in streams and pools provided with running water, mostly above 1,400 feet and up to an altitude of 3,600 feet. The general appearance and attitudes of these crustaceans, as shown in Miss Manton's colored plates, are very much like those of such apterygote insects as *Machilis* and its relatives; but we must be cautious of assuming any close relationship between insects and crustaceans, though their appearance and even their structure may be in some cases strikingly parallel. However, *Anaspides* and *Paranaspides* are relatively primitive members of the group of crustaceans (Malacostraca) that includes the shrimps, crayfish, and crabs, and a study of their mouth parts will give a very plausible suggestion of how some of the structural features of insect mouth parts may have been evolved from ordinary leg structures. The feeding habits of *Anaspides* and its relatives, described by Cannon and Manton (1929), are of course different from those of any insect, but functional differences do not often obscure fundamental structural similarities.

Through the interest of Dr. Waldo L. Schmitt, of the United States National Museum, the writer has been able to make a personal study of specimens of *Anaspides tasmaniae* (fig. 16). As already shown in the description of the head, the large mandibular segment of *Anaspides* (*B*, *IV*) is followed by a composite segment (*V*+*VI*+*VII*) bearing two pairs of maxillae (*1 Mx*, *2 Mx*) and the first pair of maxillipeds (*1 Mxp*). The maxillipeds are typical, leglike appendages, each composed of seven segments (fig. 17 A). The first segment is the basis (*LB*), usually called the *coxopodite* (*Cxpd*) by students of Crustacea. The next three segments are the first

and second trochanters (*1Tr*, *2Tr*) and the femur (*Fm*). At the end of the femur is a kneelike bend in the limb, followed by the

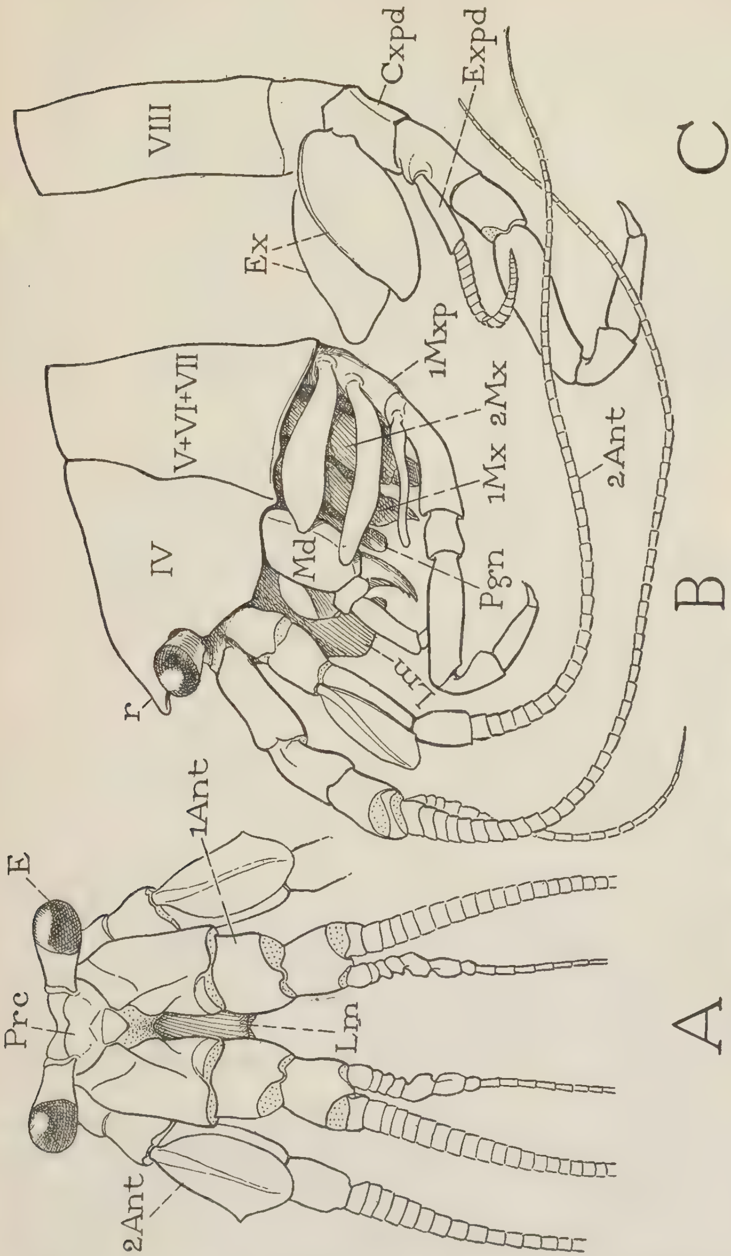

FIGURE 16.—*Anaspides tasmaniae* (primitive malacostracan crustacean)

A, anterior view of the procephalon and its appendages. B, anterior end of the body, showing the large tergal plate of the mandibular segment (*IV*) produced into the rostrum (*r*) between the eyes, and the single tergal plate of the two maxillary and first maxilliped segments (*V+VI+VII*). C, second maxilliped and the tergum (*VIII*) of its segment. *1Ant*, first antenna; *2Ant*, second antenna; *Cxpd*, coxopodite; *E*, compound eye; *Ex*, exite lobes of coxopodite; *Expd*, exopodite; *Lm*, labrum; *Md*, mandible; *1Mx*, first maxilla; *2Mx*, second maxilla; *1Mxp*, first maxilliped; *Pgn*, paragnath; *Prc*, procephalon; *r*, rostrum.

tibia (*Tb*), the tarsus (*Tar*), and the praetarsus (*Ptar*). The segments evidently correspond with the segments of an insect's leg, and are therefore here named according to the entomological leg

nomenclature. The shaft of the limb beyond the basis constitutes the telopodite.

The most important feature of the first maxilliped of *Anaspides*, for our present purpose, is the presence of lobes borne on its basal parts. Viewed from the side (fig. 17 A) it is seen that the basis carries two long exite lobes (*1Ex*, *2Ex*), and that a third exite (*3Ex*) arises from the proximal end of the first trochanter. Turning the limb outward (B), it is to be observed, furthermore, that the basis is provided also with two mesal lobes, or endites. The first endite we may call the *lacinia* (*Lc*), and the second the *galea* (*Ga*), since these are familiar entomological names for similar lobes of the maxillae. Considering, now, that there are two exite lobes and two endite lobes on the maxilliped basis, it might be argued that the apparent single basal segment of the appendage is really formed by the union of two more primitive segments, each provided

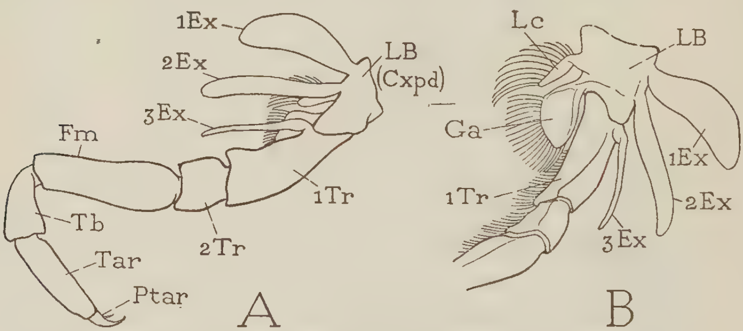

FIGURE 17.—First maxilliped of *Anaspides tasmaniae*
A, outer view of left appendage. B, anterior view of base of same. *Ex*, exite lobes; *Ga*, galea; *Lc*, lacinia. Other lettering as on Figure 15.

with an exite and an endite. If this is really the case, the basis, or coxopodite, of the maxilliped is composed of a coxa and a subcoxa, which have become united. There are certain other theoretical reasons for believing that the basis is a compound segment, but the visible facts do not in themselves give support to the idea, and the writer prefers to take the facts at their face value. The basis, therefore, is here assumed to be a single segment bearing two exite lobes and two endite lobes.

The two pairs of appendages that precede the maxillipeds are the first and the second maxillae. The maxillae are small, flat appendages (fig. 18 C, D, E) having no suggestion of the leglike form of the maxillipeds, but on close inspection it is to be seen that each differs from a maxilliped simply in the reduction of the telopodite (*Tlpd*) and in an elaboration of the basis. In other words, each maxilla is mostly the basis of an appendage, bearing the two endite lobes (*Lc*, *Ga*) but having no exites, and supporting a rudimentary

telopodite. The appendage is attached to the body in such a way that its principal motion is in a transverse plane, and its strongest muscles are the adductors (*KL*).

The second maxilla (fig. 18 C) has in some respects a more simple structure than the first. The dorsal part of its outer wall is bent toward the articulation with the lateral wall of the body, evidently to give more effectiveness to the groups of adductor muscles (*KL*)

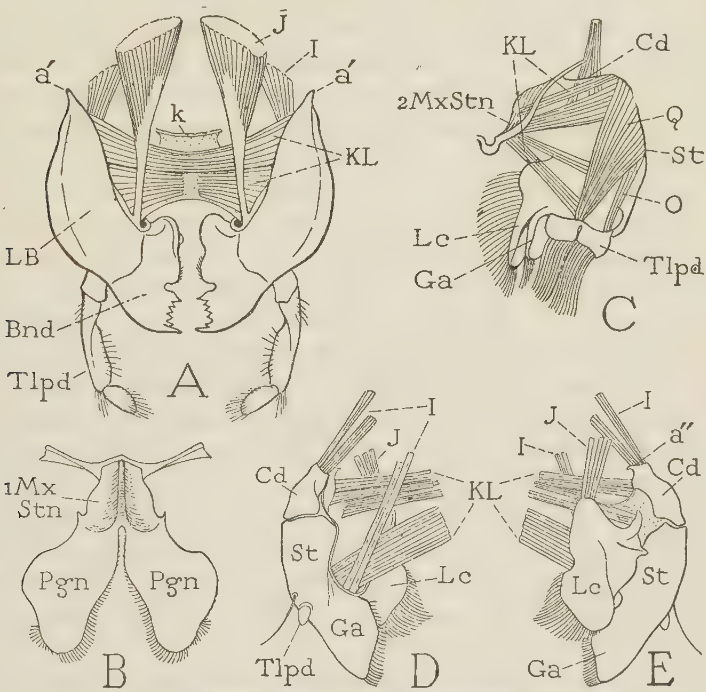

FIGURE 18.—Mouth appendages of *Anaspides tasmaniae*

A, mandibles, posterior view. B, paragnatha, posterior view. C, second maxilla, right, anterior view. D, first maxilla, right, anterior view. E, second maxilla, right, posterior view. *a'*, basal articulation of mandible; *a''*, basal articulation of first maxilla; *Bnd*, basendite; *Cd*, cardo; *Ga*, galea; *I*, dorsal promotor; *J*, dorsal remotor; *k*, ligamentous membrane; *KL*, ventral adductors; *LB*, limb basis; *Lc*, lacinia; *1MxStn*, first maxillary sternum; *2MxStn*, second maxillary sternum; *O*, levator of telopodite; *Pgn*, paragnatha; *Q*, depressor of telopodite; *Tlpd*, telopodite.

which arise on a sternal plate (*2MxStn*) in the ventral wall of the body. The basis of this maxilla is thus mechanically differentiated into a proximal part (*Cd*) and a distal part (*St*), which may be termed *cardo* and *stipes*, respectively, since they suggest the parts so-named in the maxilla of an insect. The maxillary endites of *Anaspides* (*Lc*, *Ga*) appear to have no muscles; but the small, one-segmented telopodite (*Tlpd*) is provided with two muscles (*O*, *Q*) taking their origins in the stipital region (*St*) of the appendage.

The first maxillae (fig. 18, D, E) have a structure similar to that of the second maxillae, but they differ from the latter in a number of details. The body of the appendage is divided by a distinct line of articulation between the cardo (*Cd*) and the stipes (*St*), and is provided with strong sternal adductor muscles (*KL*) inserted on both the cardo and the stipes. The dorsal musculature consists of two groups of promotor fibers (*I*) and a group of remotor fibers (*J*). The promotors are inserted on the base of the cardo and on the distal end of the stipes; the remotors are inserted on the basal angle of the lacinia (E, *Lc*). The endite lobes of the first maxilla are well developed. The lacinia (*Lc*) is an independent plate attached by membrane to the stipes; but the galea (*Ga*) is a direct continuation of the distal part of the stipes. The telopodite (*Tlpd*) is reduced to a peglike rudiment arising from the stipes at the base of the galeal lobe. As we shall see, there are many points of resemblance between the first maxilla of *Anaspides* and the maxilla of an insect.

Lying immediately before the first maxillae and behind the mandibles is a pair of large, flat, transverse lobes, the *paragnatha* (fig. 18 B, *Pgn*). The paragnatha hang downward from the anterior end of the median sternal plate of the first maxillary segment, which has a median channel ending at the base of the narrow cleft between the bases of the paragnathal lobes. The possible homology of the crustacean paragnatha with the insect superlinguae has already been discussed (p. 455), and we have observed that the paragnatha in some Crustacea are intimately associated with a median sternal lobe (fig. 7 C), the three forming a composite organ much resembling the insect hypopharynx, and having the same situation between the mandibles and the first maxillae.

The mandibles of *Anaspides* are strong jaws (fig. 18 A) suspended from the mandibular segment, to which each is articulated by a single dorsal point of articulation (a') with the inner surface of the overlapping lateral lobe of the tergum. Ventrally the free end of each jaw is produced into a large lobe (*Bnd*), subdivided into a distal, toothed incisor part, and a heavier, proximal molar part. Laterad of the base of the terminal lobe arises a three-segmented telopodite, or *palpus* (*Tlpd*). It is clear that each mandible of *Anaspides* consists of the limb basis of an appendage (*LB*), bearing a large, immovable endite lobe (*Bnd*), and of a small, segmented telopodite (*Tlpd*). The mandibular basis shows no subdivisions corresponding with the cardo and stipes of a maxilla.

The musculature of the *Anaspides* mandibles is characteristic of the musculature of all arthropod mandibles that are movable on single points of articulation. Each jaw is provided with two dorsal muscles (fig. 18 A) and strong ventral muscles. The dorsal muscles

consist of an anterior promotor muscle (*I*) and a posterior remoter muscle (*J*), both arising on the tergum of the mandibular segment and inserted on opposite edges of the mandible. These two muscles evidently serve to rotate the jaw, or to swing it forward and backward on its dorsal point of articulation (*a*). The ventral muscles (*KL*) are adductors. They consist of two groups of fibers. The fibers of a dorsal group form a flat muscle band extending continuously across the median line from one mandible to the other. The fibers of a much larger ventral group for each jaw arise medially on a ventral ligamentous membrane (*k*) between the mandibles, and diverge laterally to their insertions within the cavity of the mandible. The supporting membrane apparently arises from the ventral wall of the mandibular segment; it turns posteriorly over the adductor muscles, where it gives attachment to several small muscles not connected with the mandibles, and is suspended by a number of slender ligaments arising dorsally on the mandibular tergum. The jaws have no muscles antagonistic to the adductors; they probably relax by the elasticity of their connections with the body.

VI. GENERAL STRUCTURE OF A GNATHAL APPENDAGE

The study of the mouth parts of *Anaspides* leaves little doubt that the maxillae and the mandibles have been derived from appendages resembling the first maxillipeds, which latter, in turn, are clearly but slightly modified legs. The essential difference between a gnathal appendage and a locomotory appendage is that, in the former, the emphasis is placed on the basis, while in the latter it is given to the telopodite.

In the maxillae, as clearly shown in *Anaspides* (fig. 18 C, D, E), the basis of each appendage is differentiated for mechanical efficiency into a proximal cardo, and a distal stipes. The distinction between these two parts of the basis is a characteristic feature of the maxillae of all insects (figs. 19, 21 C, *Cd*, *St*). The basis of the mandible in *Anaspides* (fig. 18 A) is undivided, as it is also in all other crustaceans and in the insects and the centipedes (Chilopoda). In the millipedes (Diplopoda), however, the mandibular basis is subdivided into two parts apparently corresponding with the cardo and stipes of a maxilla. Hence, we might infer that the differentiation of the basis into a proximal and a distal part was a primitive character of all the gnathopods, though, on the other hand, if we assume that the subdivision of the basis is a secondary mechanical adaptation, it is possible that the cardo and stipes have been independently differentiated in the diplopod mandibles, and possibly also in the maxillae of insects and crustaceans.

The presence of endite lobes on the basis is particularly characteristic of the gnathal appendages. The presence of two such lobes, lacinia and galea, is typical of the maxillae of crustaceans and insects (fig. 19, *Lc*, *Ga*). The maxillary lobes are usually movable. When the lobes are provided with muscles, the muscles always (in insects,

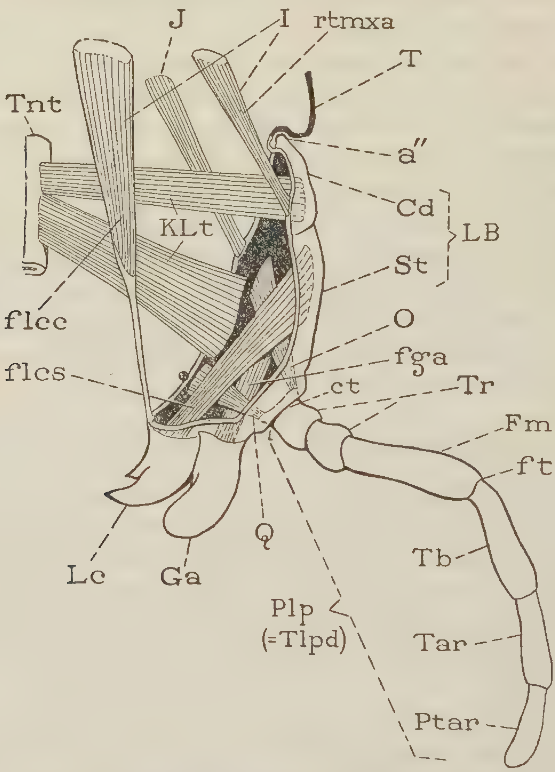

FIGURE 19.—Diagram of the structure and musculature of the first maxilla of an insect

a'', basal articulation with cranium; *Cd*, cardo; *ct*, coxo-trochanteral joint; *fga*, flexor of galea; *flcc*, cranial flexor of lacinia; *flcs*, stipital flexor of lacinia; *Fm*, femur; *ft*, femoro-tibial joint; *Ga*, galea; *I*, dorsal promotors; *J*, dorsal remotor; *KLt*, tentorial adductors; *LB*, limb basis; *Lc*, lacinia; *O*, levator of palpus; *Plp*, palpus; *Ptar*, praetarsus; *Q*, depressor of palpus; *rtmxa*, anterior rotator of maxilla; *St*, stipes; *Tar*, tarsus; *Tb*, tibia; *Tlpd*, telopodite, or palpus; *Tnt*, tentorium; *Tr*, trochanters.

at least) take their origin in the stipes (*flcs*, *fga*), except a muscle often associated with the lacinia (*flcc*), which arises on the head wall, and therefore apparently belongs to the dorsal promotor system (*I*) of the basis.

The mandibles have each only a single terminal lobe. In the Diplopoda the mandibular lobe is freely movable on the basis, and is

provided with muscles like those of a maxillary lacinia; in the chilopods it is likewise movable on the basis, but is not so definitely articulated with the latter as in the diplopods; in the Crustacea and insects the mandibular endite is always amalgamated with the basis, and the jaw thus becomes a single, unified appendicular organ without movable parts (fig. 20). The most simple representatives of the mandibular appendages occur in the Chelicerata, in which the organs have the form of shortened legs, called the pedipalps. The basal segment of each pedipalp, however, may have a large endite lobe closely associated with the mouth.

Considering the mouth parts of the Arthropoda generally, there can be little doubt that the mandibles as well as the maxillae have been evolved from leglike appendages. It seems highly probable, moreover, that in the Mandibulata the mandibles first attained a structure similar to that of the insect maxillae, but, being the most anterior in the series of gnathal appendages, they have since departed more radically from the typical structure in their evolution into biting and chewing jaws. The first maxillae of insects, in their more generalized form, would appear to retain very closely the primitive structure of a gnathal appendage. The crustacean maxillae are generally more reduced and simplified than those of biting insects; the maxillae of the chilopods evidently have never departed far from the leg structure; the corresponding appendages of diplopods are so highly specialized that it is impossible to judge what their primitive structure may have been.

The structure and musculature typical of an insect maxilla is shown diagrammatically in Figure 19. The similarity to the maxillae of *Anaspides* (fig. 18 D, E) is striking. The reduction of the telopodite in the maxillae of *Anaspides* is a mere detail—the maxillary palpi are better developed in some other Crustacea. In the insect maxilla the body of the appendage, or basis (fig. 19, *LB*), is membranously attached to the lateroventral aspect of the head by its entire inner margin, but it is definitely suspended from the lateral ventral margin of the cranium by a single dorsal point of articulation (a'') on the base of the cardo. The cardo (*Cd*) and stipes (*St*) are separated by a distinct suture, or line of flexibility, which ends in the basal margin of the appendage. The cardo and stipes thus do not have the relation of segments to each other. The stipes bears distally a movable lacinia (*Lc*), and a movable galea (*Ga*). The telopodite, or palpus (*Tlpd*), is generally well developed; the number of its segments is variable, but the segmentation suggests that of a leg (fig. 15 C).

The musculature of a maxilla includes *extrinsic* and *intrinsic* muscles. The extrinsic muscles arise on the head wall, or on endo-

skeletal processes of the cranium, and are inserted on the cardo and the stipes. The principal extrinsic muscles are the adductors (fig. 19, *Klt*), the fibers of which arise on the tentorium (*Tnt*), and are inserted within the cardo and stipes. They are evidently the primitive ventral promoters and remoters of a generalized limb (fig. 14, *K*, *L*), the origins of which have been carried into the head with the development and transposition of the anterior arms of the tentorium. The other extrinsic muscles are usually but two in number. One is an anterior rotator of the maxilla (fig. 19, *rtmxa*) inserted on the cardo anterior to the articulation (a'') of the latter with the head; the other (*flcc*) is inserted at the base of the lacinia, and functions as a cranial flexor of the lacinia. These two muscles appear to represent the dorsal promotor of a generalized limb (fig. 14, *I*). A representative of the dorsal remotor is generally absent from the maxilla, but it is indicated in the diagram (fig. 19, *J*) because it is an important muscle of the mandible, and is sometimes retained in the maxillary musculature as a posterior rotator inserted on the cardo. The intrinsic muscles of the maxilla include the muscles of the endite lobes (lacinia and galea) and the muscles of the palpus, all of which take their origins *within the stipes.* The muscles of the lobes (*flcs*, *fga*) never include antagonistic pairs of muscles; the palpus muscles, on the other hand, nearly always consist of a levator (*O*) and a depressor (*Q*), corresponding with the muscles of the telopodite of a leg inserted on the base of the first trochanter (fig. 15, A, B, *O*, *Q*).

It will be shown in the following section how the mandibles and the second maxillae (labium) conform with, and depart from, the more generalized structure of a typical first maxilla.

VII. THE BITING TYPE OF INSECT MOUTH PARTS

When the gnathal appendages gave up their primitive function as organs of locomotion, and became transferred to the head in the capacity of organs accessory to ingestion, the mandibles, being closest to the mouth, were undoubtedly the first to undergo structural modifications in adaptation to their new duties. At first they probably served as mere prehensile or grasping appendages for obtaining the food and for passing it into the mouth; but in the Crustacea and Hexapoda they eventually evolved into strong biting and chewing jaws, and lost all semblance to their former leglike structure, except in the retention of the palpi in some of the crustaceans. The first maxillae, on the other hand, did not so completely lose their primitive form until, in some of the piercing and sucking insects, they became highly specialized as parts of an apparatus for feeding on liquid food. The second maxillae have had a more eventful history

in insects, because at an early evolutionary period they were united with each other forming the median, posterior appendicular organ of the head known as the labium, which has since undergone many special modifications in its structure. The labrum and the hypopharynx have been least affected in the evolution of the mouth parts, but even these organs in some of the piercing insects have suffered radical changes of form in compliance with special functions they have assumed.

In the following descriptions there will be discussed only the fundamental modifications of the primitive mouth parts that have given these organs their typical structure in the so-called biting and chewing insects.

The labrum.—The labrum in its typical form, as seen in the cricket, (figs. 9 A, *Lm*, 21 A), is a broad flat lobe movable by a transverse line of flection on the lower edge of the clypeus. The muscles of the labrum take their origin on the frons. In generalized insects there are two pairs of them, one pair (fig. 21 A) inserted anteriorly, the other posteriorly, on the labral base, the posterior pair being usually attached on small bars known as the *tormae*. In the cricket the anterior labral muscles are united into a single bundle of fibers. The posterior wall of the clypeus is often elevated in the form of a median lobe, of various shapes in different insects, called the *epipharynx* (fig. 4, *Ephy*).

The mandibles.—The mandibles are the jaws of ordinary biting insects. Their primary structure as jaws is seen in some of the apterygote insects (fig. 2 B, *Md*), where they closely resemble the mandibles of the more generalized crustaceans, such as the phyllopods (fig. 2 A, *Md*), and *Anaspides* (fig. 18 A). The insect mandibles differ from the crustacean mandibles in that they always lack palpi.

A generalized mandible of the apterygote insect type of structure is an elongate organ, implanted by the broad inner surface of its base on the membranous lateroventral wall of the head (fig. 2 B, *Md*), to which it is hinged by a *single* dorsal point of articulation (a'). The jaw is moved by dorsal and ventral muscles. The dorsal muscles comprise two distinct fiber bundles arising on the dorsal wall of the head, one inserted anteriorly on the base of the mandible (fig. 20 A, *I*), the other (*J*) posteriorly. These muscles, therefore, are the primitive dorsal promotor and the dorsal remotor of the appendage (fig. 14, *I*, *J*.), and probably serve to rotate the mandible on its long axis. The ventral muscles, which are functionally adductors, usually comprise two groups of fibers (fig. 20 A, *KL*) arising within the hollow of the mandible. Those of one group (*KLz*) are attached on a median ligament (*z*), and the fibers from

the opposite jaws thus pull against each other, the whole structure forming a zygomatic mandibular adductor. Those of the other group (*KLt*) arise on a pair of sternal processes (*HA*), which are clearly the prototypes of the anterior tentorial arms of pterygote insects. The ventral muscles, considered as a single functional group of fibers, evidently represent the ventral promotors and remotors of a generalized limb (fig. 14, *K*, *L*), and hence are collectively designated *KL*, as in Figures 18, 19, and 20.

In the pterygote insects, and in some of the Apterygota, the mandibles have a quite different type of mechanism from that characteristic of an apterygote mandible. Each jaw has a broad base, and, instead of a single dorsal point of articulation, it has a long hinge

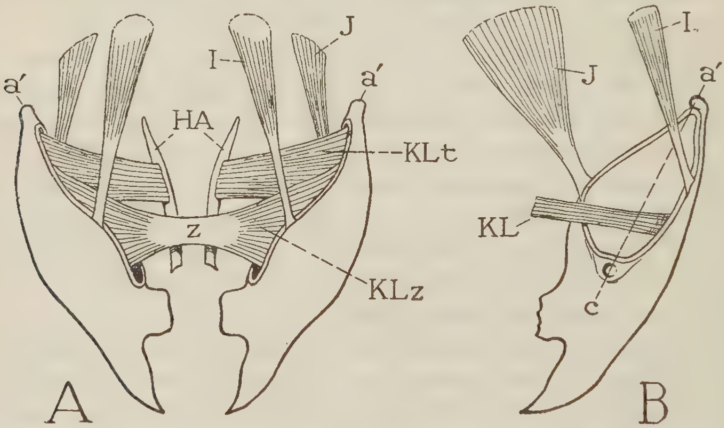

Figure 20.—Diagrams of typical apterygote (A) and pterygote (B) mandibles

a′, primary articulation with cranium; *a′–c*, secondary longitudinal axis of movement on cranium; *HA*, hypopharyngeal apophyses (anterior tentorial arms); *I*, dorsal promotor; *J*, dorsal remotor; *KLt*, tentorial adductors; *KLz*, zygomatic adductor; *z*, ligament of zygomatic muscle.

line on the lower lateral margin of the cranium (fig. 12 A, *Md*) between strong *anterior* and *posterior* articulations with the latter (fig. 8, *c*, *a′*). The posterior articulation (fig. 20 B, *a′*) represents the primary dorsal articulation (A *a′*). The anterior articulation (B, *c*) is a secondary one; its acquisition limits the movement of the appendage to that of a hinge with a longitudinal axis (*c-a′*). By this change in the articulation of the mandible, the muscles assume altered functions. The primitive dorsal promotor (A, *I*) becomes a dorsal adductor (B, *I*), and the primitive remoter (A, *J*) becomes a dorsal adductor (B, *J*). The ventral adductor muscles are either greatly reduced or are entirely obliterated in the Pterygota. Remnants of them (B, *KL*) persist, however, in some of the more generalized pterygote insects, as in the mandibles of the cricket and some other Orthoptera, where the ventral adductors are repre-

sented by small groups of fibers (fig. 21 B, *KLt*) arising on the tentorium, or at the base of the hypopharynx. Since the mandibles usually do their hardest work with the inward movement, the dorsal

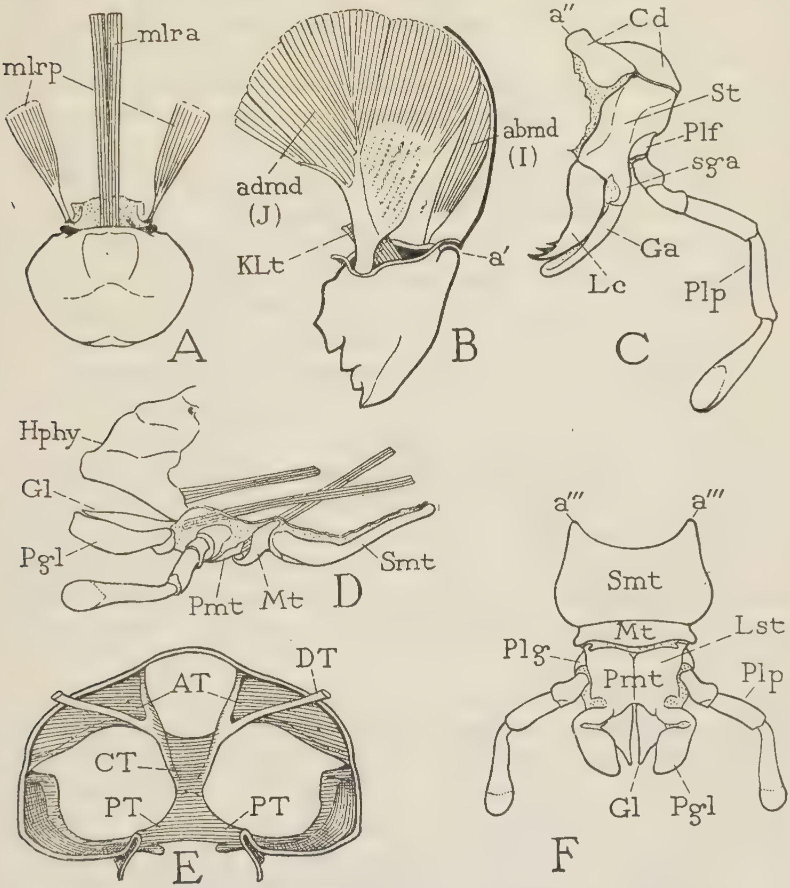

FIGURE 21.—Mouth parts and tentorium of a cricket, *Gryllus assimilis*

A, labrum and muscles, anterior view. B, right mandible and muscles, posterior view. C, right maxilla, posterior view. D, hypopharynx and labium, lateral view. E, tentorium, dorsal view. F, labium, posterior view. *a′, a″, a‴*, articulations of mandible, maxilla, and labium with cranium; *admd*, adductor of mandible; *abmd*, abductor of mandible; *Cd*, cardo; *CT*, corpotentorium; *DT*, dorsal arm of tentorium; *Ga*, galea; *Gl*, glossa; *Hphy*, hypopharynx; *KLt*, tentorial adductor of mandible; *Lc*, lacinia; *Lst*, labiostipites; *mlra, mlrp*, anterior and posterior labral muscles; *Mt*, mentum; *Pgl*, paraglossa; *Plf*, palpifer; *Plg*, palpiger; *Plp*, palpus; *Pmt*, prementum; *PT*, posterior arm of tentorium; *Smt*, submentum; *St*, stipes.

adductor muscles are commonly very large and powerful (fig. 21 B, *admd*), while the abductors (*abmd*) are small and relatively weak. Both dorsal muscles are generally inserted on apodemal stalks or plates, which are not attached directly to the mandibles, but arise from the articular membrane close to the edge of the mandible.

The maxillae.—The first pair of maxillary appendages of insects are usually called "the maxillae," because the second pair are united in the labium. The maxillae in their typical form are the most leglike of the gnathal appendages. The usual structure of a maxilla of biting insects is well illustrated in the maxilla of the cricket, shown in Figure 21 C, which presents the posterior surface of a right appendage. The anterior wall is less complete, because the maxilla is broadly attached by most of the anterior surface of its basal part to the wall of the head. The basis of the appendage is divided into the proximal cardo (*Cd*) and the distal stipes (*St*). The stipes bears laterally the long palpus (*Plp*), and distally the two endite lobes, lacinia (*Lc*) and galea (*Ga*). A lobe of the stipes supporting the galea is sometimes distinguished as the *subgalea* (*sga*), and a more or less differentiated lateral lobe bearing the palpus is known as the *palpifer* (*Plf*). The cardo is usually divided externally by the line of a strong internal ridge, and the area of the stipes may also be marked by external grooves, or "sutures," that form internal strengthening ridges.

The maxilla is always articulated to the hypostomal rim of the cranium by a single point of articulation (fig. 8, *a''*) borne on the base of the cardo (fig. 21 C, *a''*). It thus preserves the primitive single articulation with the head, which corresponds with the primitive mandibular articulation (figs. 2 B, 20 A, *a'*), or with the posterior articulation of the mandible in pterygote insects (fig. 20 B, *a'*).

The musculature of the maxilla is so nearly identical with that described in the last section for a generalized gnathal appendage (fig. 19) that it need not be described in detail here. Usually there are only two maxillary muscles arising on the dorsal part of the cranium, both of which (*I*) apparently belong to the dorsal promotor system of a primitive appendage (fig. 14, *I*), though they are widely separated on the anterior margin of the maxillary base. One is inserted on the cardo (fig. 19 *rtmxa*), the other at the basal angle of the lacinia (*flcc*); the latter functions, therefore, as a cranial flexor of the lacinia. The dorsal remotor (*J*) is usually lacking, but is sometimes present as a posterior muscle of the cardo. The ventral muscles (*KLt*) are powerful adductors. They take their origin on the tentorium, and are inserted within both the cardo and the stipes. The intrinsic muscles of the maxilla all arise within the stipes. They comprise a levator and depressor of the palpus (O, *Q*), a flexor of the galea (*fga*), and a stipital flexor of the lacinia (*flcs*).

The disposition of the maxillary muscles leaves little doubt that the cardo and stipes are but secondary subdivisions of the primitive

basis of the appendage, and that they do not represent true limb segments, as some writers have supposed. The same conclusion, as we have seen, is even more strongly suggested by a study of the maxillae of the crustacean *Anaspides* (fig. 18, C, D, E) in which the cardo and stipes are clearly but differentiated parts of the basis, which in the maxilliped (fig. 17, *LB*) is an undivided segment. The origin of the palpus muscles (fig. 19, *O*, *Q*) in the mesal part of the stipes and the origin of the galea muscle (*fga*) in the base of the stipes also leave no support for the idea, held by some writers, that the palpifer (fig. 21, C, *Plf*) is a segment of the appendage bearing the palpus and the galea. The two small basal segments of the palpus (fig. 19, *Tr*), therefore, belong to the trochanteral region of the telopodite, and the basal articulation of the proximal

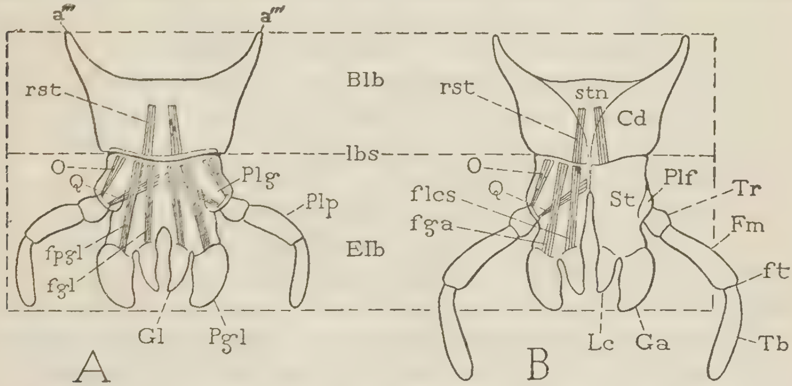

FIGURE 22.—Diagrams comparing the labium with a pair of united maxillae

A, a primitive 2-part labium and its internal muscles. B, a pair of second maxillae as theoretically united with each other and with a part of the labial sternum. *Blb*, basilabium; *Elb*, eulabium; *lbs*, labial suture; *stn*, labial sternum. Other lettering as on Figures 19 and 23.

one (*ct*) corresponds with the coxo-trochanteral joint of a leg (fig. 15 C, *ct*), or with the baso-telopodite joint of a primitive limb (A, *ct*).

The labium.—The labium is an insect specialty. Though a pair of head appendages may be united in some of the other groups of Arthropoda, the union has not produced an organ equal to that evolved from the second maxillae by the insects. While it is well known that the insect labium contains the second maxillary appendages, it is not certain that it does not include also a part of the ventral wall of the labial segment of the head. There are, in fact, several reasons for believing that the proximal part of the labrum is a composite structure, consisting of the maxillary cardines and a median part of the labial sternum; but a discussion of these reasons can be better presented after describing the general structure of the labium.

The labium in its simplest generalized form (fig. 22 A) is divided by a transverse suture, or line of flexibility (*lbs*), into two principal parts, one proximal, the other distal. The distal part has been termed the *eulabium* (*Elb*) by Crampton (1928). In a functional sense, at least, it is the "true" labium, i. e., the under lip of the insect, though it is perhaps not the entire second maxillae as Crampton implied. The proximal, basal part of the labium may be called the *basilabium* (*Blb*). The basilabium is generally not a free part of the labium, since it is usually implanted by most of its extent on the posterior ventral wall of the head, anterior to the neck. Its lateral basal angles (a'''), however, are attached to the ventral margin of the cranium (fig. 3 A) just behind the posterior tentorial pits (*pt*) in line with the articulations of the maxillae (*Mx*) and the mandibles (*Md*). The body of the eulabium (fig. 22 A, *Elb*) hangs as a free flap from the distal edge of the basilabium. It bears all the appendicular parts of the labium, including a pair of lateral palpi (*Plp*), and four terminal lobes (*Gl*, *Pgl*). The eulabium is sometimes deeply divided between the median pair of terminal lobes (fig. 23), but the cleft never extends into the basilabium.

The identities of the parts of the labium, as compared with the parts of a pair of united maxillae, can be established only by a study of the labial musculature. The principal internal muscles of the labium (fig. 22 A) consist of levators and depressors of the palpi (*O*, *Q*), flexors of the terminal lobes (*fgl*, *fpgl*), and retractors of the eulabium (*rst*). The muscles of the palpi and the terminal lobes take their origins within the body of the eulabium; the retractors of the eulabium (*rst*) arise medially in the basilabium, and are inserted on the proximal margin of the eulabium.

A comparison of the labial musculature (fig. 22 A) with that of a maxilla (B) shows at once that the body of the eulabium is the stipital region (*St*) of the united second maxillae. The body of the eulabium, therefore, is the *pars stipitalis labii*, and is correctly named *stipites labialis*, or *labiostipites*. Lateral lobes of the labial stipites supporting the palpi (A, *Plg*) are equivalent to the palpifers of the maxillae (B, *Plf*), but are sometimes distinguished as *palpigers* (*Plg*). The terminal lobes of the labium are called *glossae* (A, *Gl*) and *paraglossae* (*Pgl*); they clearly correspond with the laciniae and galeae of a pair of maxillae (B, *Lc*, *Ga*). Sometimes the two labial lobes on each side are united, sometimes the two median lobes are fused, or again all four may be unified in a single flap. The terminal lobes collectively constitute the *ligula* (fig. 24, *Lig*).

The morphology of the basilabium is much more difficult to determine than that of the eulabium. Some writers believe that the suspensory plate of the eulabium is the sternum of the labial segment.

The attachment of the basilabium on the lower margin of the cranium by its basal angles in line with the cranial articulations of the maxillae and mandibles (fig. 3 A), however, would suggest that the basilabium contains the cardines of the second maxillae (fig. 22 B. *Cd*). On the other hand, the origin of retractor muscles of the labiostipites on the basilabium (figs. 22 A, 24, *rst*) makes it seem unlikely that the labial base is formed of the cardines alone, since there are never cardino-stipital muscles in the first maxillae; but if the basilabium contains a median sternal element (fig. 22 B, *stn*), these muscles might be sterno-stipital muscles without objection. In the Dermaptera (fig. 25 A) a pair of large ventral muscles of the hypopharynx (*mhv*) also take their origin on the basilabium. Furthermore, the opening of the salivary duct, which originates in the embryo on the labial sternum between the bases of the second maxillae, is situated in generalized adult insects anterior to the base of the eulabium (fig. 4, *SlO*), and this fact suggests that the primitive labial sternum has been constricted between the approximated bases of the appendages while the salivary opening was crowded forward between the latter. Finally, the basal part of the labium is never divided medially, though the stipital region may be split almost completely into its lateral components.

A concrete example indicating the composite nature of the basilabium is seen in the labium of *Machilis* (fig. 23 A): A pair of faintly marked but distinct lines converge distally in the basilabium, subdividing the latter according to the very pattern we might suppose would result from the fusion of the cardines with a posterior median part of the labial sternum (fig. 22 B).

According to Holmgren (1909), the entire basal plate of the labium in termites, which is greatly elongate in the soldier caste (fig. 24 B, *Bmt*), is formed as a sclerotization of the neck membrane behind the bases of the second maxillary appendages, which latter move forward during the course of development. As to the fate of the cardines, Holmgren is uncertain, though he suggests that they perhaps are lost in the membrane between the eulabium and the basal plate. In the termite soldier the posterior tentorial pits are stretched out almost to the distal end of the basilabium, so that here the cardinal parts of the labium must in any case be very small, but this condition does not pertain to the usual structure characteristic of most insects.

While there can be little doubt that the labium is fundamentally a two-part structure, the sclerotization of its exposed posterior wall is seldom so simple and has been the cause of much confusion in labial nomenclature. The region of the basilabium may be entirely membranous or wholly sclerotized; its sclerotization may take the

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form of one, two, or even three distinct plates. In the stipital region there may be two separate lateral sclerites, though generally most of the stipital area is covered by a single plate.

When the basilabium contains two distinct plates (fig. 23 D), the distal one is generally termed the *mentum* (*Mt*), and the proximal

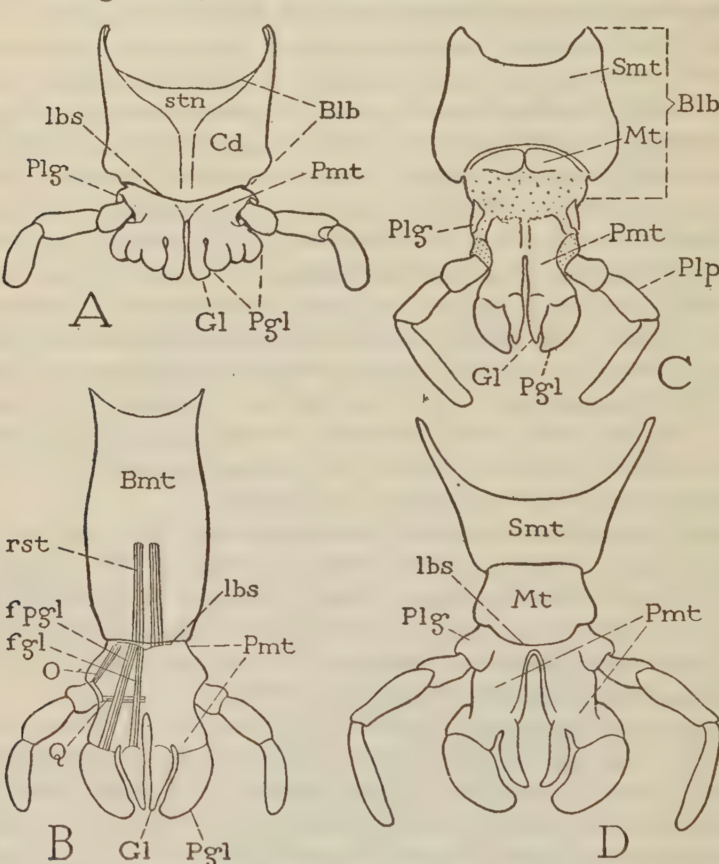

FIGURE 23.—Various types of labial structure

A, *Machilis*, showing faint subdivision of basilabium (*Blb*) into lateral and median areas (*Cd*, *stn*). B, soldier of *Termopsis*, with a single large plate, the postmentum (*Bmt*), in the basilabial region. C, *Blatta orientalis*, with reduced mental sclerites (*Mt*). D, *Scudderia*, a typical 3-part labium. Lettering as on Figure 24.

one the *submentum* (*Smt*). The stipital sclerotization is then called the *prementum* (*Pmt*). Some entomologists, however, especially those studying insects having a single basal plate, give the name " mentum " to the stipital plate, and term the basal plate the " submentum." This system, as Kadić (1902) and Walker (1931, 1931a) have shown, is the most logical nomenclature that can be applied to the labium, since it is based on the primitive structure retained

in such insects as Apterygota (fig. 23 A), Isoptera (B), Odonata, Diptera, the larvae of Lepidoptera and Hymenoptera, and others. When there are two sclerites in the basal region Walker would distinguish the proximal one as the *primary submental plate*, and the distal one ("Vorderplatte" of Kadić) as the *secondary submental plate.*

While agreeing in spirit, and in former usage (1928), with the plan of labial nomenclature advocated by Kadić and by Walker, the writer here follows the more common practise of giving the names "mentum" and "submentum" to the two principal plates that may be formed in the region of the basilabium. This usage, however, leaves us without an appropriate name for a primitive single sclerite occupying the basilabium, or for one that can not be certainly identified with either the submentum or the mentum. For a sclerite of this nature the term *postmentum* (fig. 23, B, *Bmt*) is suggested. It would appear in some cases that the mentum and submentum are differentiations from a primitive postmentum, and in others that the mentum is formed from the membranous anterior part of the basilabium. In any case, however, the mentum belongs to the sub-stipital region of the labium, since it always lies proximal to the insertions of the retractor muscles of the stipites (fig. 24, *rst*) inserted on the base of the prementum. The mentum in some insects evidently has suffered a secondary reduction, as in the Blattidae (fig. 23 C, *Mt.*); in the Acrididae it is practically obliterated.

The complete musculature of the labium (fig. 24) comprises four groups of muscles. Those of the first group include two pairs of muscles arising typically on the tentorium, both of which are inserted on the prementum, one pair proximally (*1adlb*), the other distally (*2adlb*). These muscles correspond with the tentorial adductors of the first maxillae (fig 19, *KLt*). The second set of labial muscles includes the muscles of the palpi (fig. 24, *lplp*, *dplp*), and of the terminal lobes (*fgl*, *fpgl*), all of which arise within the prementum, and have their exact counterparts in the maxillae (fig. 19, *O*. *Q*, *flcs*, *fga*). The third group of labial muscles includes two pairs (fig. 24, *1s*, *2s*) arising within the prementum and inserted on or near the orifice of the salivary duct. These muscles are not represented in the maxillae. The labial muscles of the fourth set are the stipital retractors (fig. 24, *rst*) arising medially on the basilabium (always proximal to the mentum when the latter is present), and inserted on the extreme base of the prementum. These are important muscles of the labium, but they have no representatives in the maxillae.

Lastly, we must observe what happens to the labium in insects having a prognathous type of head (fig. 12 B), and particularly in

insects of this kind in which the posterior part of the head is elongate.

A simple elongation of the posterior part of the head, unaccompanied by structural changes in the cranium, has no other effect on the labium than a mere lengthening of the basilabial or submental region of the appendage. In many prognathous insects, however,

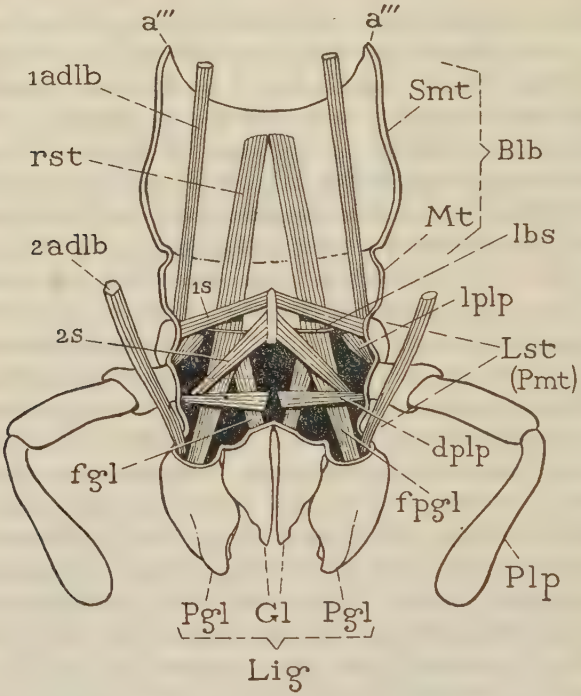

FIGURE 24.—Musculature of the labium of a cricket, *Gryllus assimilis*, anterior view

a''', articulation of labium with cranium; *1adlb*, proximal adductor of labium; *2adlb*, distal adductor of labium; *Blb*, basilabium; *dplp*, depressor of palpus; *fgl*, flexor of glossa; *fpgl*, flexor of paraglossa; *Gl*, glossa; *lbs*, labial suture; *Lig*, ligula; *lplp*, levator of palpus; *Lst*, labiostipites; *Mt*, mentum; *Pgl*, paraglossa; *Plp*, palpus; *Pmt*, prementum; *1s*, *2s*, muscles attached on base of hypopharynx near opening of salivary duct; *Smt*, submentum.

the elongation of the head has been accompanied by a forward migration of the posterior tentorial pits on the ventral head wall (figs. 12 B, 13, *pt*), with a consequent lengthening of the lower ends of the postoccipital suture (*pos*) behind the pits. In some cases, as in the soldiers of termites, the tentorial pits themselves become long, linear slits. In either case, the submental region of the labium is enlarged by an increment to its posterior part, found as an extension of its base, or gular area, lying proximal to the

tentorial pits. There is thus added to the submental region of the basilabium (fig. 13, *Smt*) a proximal area of varying extent known as the *gula* (*Gu*). Though the gula is thus but an extension of the base of the primary submentum, the two areas of the basilabium *separated by an imaginary or real line between the anterior ends of the tentorial pits* are now distinguished as "submentum" and "gula" (*Smt*, *Gu*). It is clear that the evolutionary capacity of the labium can not be made to conform with the niceties of nomenclatural consistency. In the Dermaptera (fig. 25 A) a gular plate (*Gu*) is distinctly separated from the large basilabial plate (*Bmt*), but there is no mentum present.

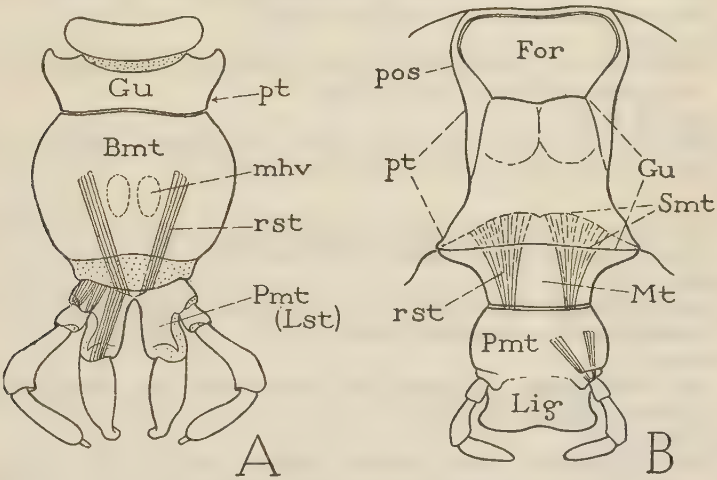

FIGURE 25.—Examples of unusual labial structures

A, labium of an earwig, *Anisolabis maritima*, with distinct gular sclerite (*Gu*) separated from a large basimental plate (*Bmt*) on which arises the stipital retractors (*rst*), and ventral muscles of hypopharynx (*mhv*). B, labium of a May beetle, *Phyllophaga*, in which the submentum (*Smt*) is inflected between the mentum (*Mt*) and the gula (*Gu*).

The necessity of studying the muscles for identifying the parts of the labium can not be overemphasized. The stipital region (prementum), as we have seen, is the part of the labium (fig. 24, *Lst*) that contains the muscles of the palpi and terminal lobes, and on which are inserted the cranial muscles of the labium. The retractors of the stipites (*rst*), when present, are always inserted on the base of the prementum, never on the mentum. A good example of the value of the muscles in determining the homologies of the labial parts is furnished by the adult May beetle (*Phyllophaga*), in which the labium (fig. 25 B) at first sight appears to have no submentum, though a distinct gula (*Gu*) and mentum (*Mt*) are present. An examination of the inner surface of the labium, however, reveals the submentum in the form of a deep inflection (*Smt*) between the

mentum and the gula, with the retractor muscles (*rst*) of the prementum (*Pmt*) taking their origins upon it.

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THE DEBT OF AGRICULTURE TO TROPICAL AMERICA[1]

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[With 7 plates]

The extent to which our present civilization has drawn upon the native agriculture of tropical America is seldom recognized and is little understood by the general public. A new consciousness and interest in civilization has developed in recent years from issues raised in the war period. It begins to be seen that the origin and growth of civilization should be studied primarily as a biological problem in order to gain a more practical understanding of the conditions and factors of human progress.

Civilization is made possible by agriculture and the best prospect of understanding civilization is through the study of agriculture. A first step toward civilization was taken when plants were domesticated and a settled existence became possible. The conditions of agriculture are required, with people living as separate families upon the land, for the experience of successive generations to accumulate, and the arts of civilization to develop. A debt of appreciation is due to the prehistoric domesticators of food plants who opened the way of advancement for the race. A poet of humanity has enjoined such a sentiment upon us, that we " forget not the forgotten and unknown." The nations have enshrined their unknown soldiers, but agriculture is a service no less than warfare.

The natives of America were inferior to the European invaders in weapons and military equipment, but in the arts of agriculture they had attained a higher development than any of the European nations. Early accounts of Mexico and Peru reflect the amazement of the Spanish explorers at the extent and perfection of the native cultures. The modern traveler shares the same feeling when he examines the remains of the ancient systems and finds that the prehistoric people went far beyond our present conceptions of agricultural possibilities. Study of the ancient systems may enlarge our ideas of improvements that are possible in agriculture. The industrial and commercial accomplishments of our civilization have

[1] Reprinted by permission from the Bulletin of the Pan American Union, September, 1930.

overshadowed our normal and instinctive interest in the welfare of agriculture. No doubt we shall find that agriculture is as necessary to maintain an advanced civilization as it was for the primitive beginnings.

The ancient Peruvians undoubtedly excelled us in the art of irrigation, and they went much further in reclamation of land. Not only were leveling and terracing done to lessen the slopes of hillsides, but also land was constructed even in places that could have had no natural soil, on precipitous slopes or in eroded stream beds. Substantial retaining walls were built and the inclosed space was filled in, below with rubble work for drainage and above with ample layers of good soil, which still raise good crops every year, after centuries of continuous cultivation. In many of the valleys of the eastern Andes all of the cultivated lands are of artificial terrace construction. Rivers were straightened and mountains resurfaced as incidents of these extensive reclamations. The narrow terraces on the slopes of the mountains, of course, have been recognized as artificial, but the vastly more extensive construction of artificial lands in the bottoms of the valleys were overlooked by many travelers, as though the terrace walls supporting the different levels were mere fences between fields. The development of such intensive methods of agriculture must have required centuries or millenniums.

DOMESTICATION OF AMERICAN PLANTS

The many plants domesticated in America are an evidence of the high development of agriculture and of the vast periods of time tha· must have been required. The Peruvian region is considered as the chief center of domestication. Between 70 and 80 different species appear to have been domesticated in pre-Spanish times, as indicated by native names and uses. The list includes numerous root and seed crops adapted to the different elevations, also fruits and vegetables, potherbs, condiments, medicines, intoxicants, fish poisons, dye plants, fibers, and numerous ornamental plants. The ancient Peruvians had potatoes, beans, maize, cotton, peppers, peanuts, cassava, and sweetpotatoes; also guavas, chirimoyas, avocados, tuberoses, marigolds, and many other fruits and flowers which are still entirely unknown in North America.[2]

Tobacco apparently was known to the ancient Peruvians, but was considered injurious. The chewing of coca leaves was a regular habit before the conquest, as it is at the present time, and an extensive culture of the coca shrub is still maintained in the eastern Andes.

[2] A list of names of Peruvian domesticated plants was published in an article on "Peru as a Center of Domestication," Journ. Hered., February and March, 1925.

Potatoes from the high altitudes, preserved by freezing and drying, are still carried down the eastern valleys on the backs of llamas and exchanged for coca. Some of the high-altitude varieties of potatoes are too bitter to be eaten in the fresh state, but are suited for drying into chuños, as the mummified potatoes are called.

The plant domestications apparently were more ancient in America than in the Old World. The lapse of time is indicated by the fact that several of the American cultivated plants are not known to exist in a wild state. Several have reached the condition of seedlessness and some have lost even the tendency to produce flowers. Many of the high-altitude crops of Peru are specialized for particular conditions and have not been established in any other countries.

The discovery and conquest of new continents beyond the Atlantic was an event that has overwhelmed and preoccupied the imagination of historians in recent centuries, but the plant treasures of the New World are still to be appreciated. Spain was in advance of other European countries at the time of discovery. The period of Arab rule in Spain had witnessed a revival or a reintroduction of many of the arts of agriculture, including irrigation, as developed in north Africa, Egypt, and Syria. Neither Spain nor the rest of Europe was able to form any conception of the importance of the new plant world of America. Only a few of our modern historic writers have perceived the significance of the discovery of a new economic flora in America as affording new materials of human advancement which the Western Hemisphere has contributed to the enrichment of our European civilization. Though only a partial utilization of the American cultivated plants has yet taken place, the entire world has profited and vastly increased its production by using plants that were domesticated in America.

That we as north Europeans should continue to attach homeland sentiments to the plants that came to America with the first settlers is partly a misunderstanding of the past. Agriculture was not original with the northern races or even indigenous in Europe, as archeological investigations have shown. The traditional Old-World cereals—barley, wheat, and rye—were not natives of any part of Europe, but of Asiatic origin. A long succession of primitive peoples have been traced in Europe, going back to the glacial periods, variously estimated from 20,000 to 100,000 years ago, but with no indications of agriculture before the so-called Neolithic people come into Europe, in the late prehistoric period, 6,000 to 10,000 years ago. Moreover, this invading race had passed the stage of first beginnings in agriculture, being proficient in irrigation, terracing, and megalithic stonework. The subsequent history of Europe was not marked by advances in agriculture, but rather by decline. In Greece, for

example, archeologists are finding that agricultural improvements of the megalithic age were not maintained in the classic period.

INTERCHANGE OF CROPS

That the world had need of the American crop plants is shown by the wide distribution that many of them have attained in Europe, Asia, and Africa. Some are grown more extensively in the Old World than in America. The potato is the chief dependence of northern Europe, and maize is a staple food in parts of Spain, Italy, Hungary, and many other countries. Cassava has become the principal root crop in parts of tropical Africa and of the East Indies. An acre of cassava is said to yield "more nutritious matter than six times the same area under wheat." The manufacture of tapioca from cassava is now conducted in the East Indies as well as in Brazil. The sweet potato was distributed across the Pacific and is well-nigh universal in tropical and subtropical regions. The peanut or ground nut is grown commercially in Senegal and in several other districts of Africa and Asia. The principal production of cacao is in West Africa. The vanilla plant grows wild in Mexico, but most of the commercial vanilla comes from the French colonies. Sisal is grown in East Africa and in the Philippines. The Hevea rubber tree, a native of Brazil, is cultivated extensively in the East Indies. Quinine and cocaine are supplied from the East Indies, though the plants are native in Peru.

Some of the Old World crops, on the other hand, are grown most extensively in America. Taking a plant to a new region may enable it to escape pests or diseases which tend to increase in long-established cultivations. The fungus which destroyed the coffee plantations of the East Indies has not reached America, where most of the world's supply of this beverage is now produced. Brazil is the great coffee country, though coffee is important also in Colombia, Venezuela, Guatemala, El Salvador, Costa Rica, Haiti, and Puerto Rico. The largest commercial cultivations of bananas are in Central America and the West Indies, whence 63,530,000 bunches were imported into the United States in 1929. More sugar is grown in Cuba than in any other country, in favorable seasons more than 5,000,000 tons being produced. Rice from Louisiana and California is shipped to tropical America, Japan, and China. Our high-priced labor raises food for low-price countries.

TROPICAL AGRICULTURE IN THE UNITED STATES

Though we are not accustomed to think of the United States as a tropical country, three of our principal crops—maize, cotton, and tobacco—are treated in European textbooks as tropical cultures and

our extensive production places us quite definitely in the tropical category. Our summer climate is essentially tropical in providing sufficient heat for the maturity of these crops. The summer heat in Europe is not sufficient to mature maize regularly north of the Alps, and only a few localities in the south of Spain, Italy, and the Balkan peninsula are warm enough for cotton. The European production of cotton in 1929 totaled about 24,000 bales, while the southern counties of Virginia produced 46,000 bales. On this basis Virginia is more tropical than the south of Europe.

The tropic of the geography passes below the southern tip of Florida, but is only a conventional imaginary line. A plant-life tropic would touch our east coast of North Carolina, follow the coast plain to Texas, and continue westward through southern Arizona and California. Botanists would not deny that countries with native palms should be reckoned as tropical. The southern palmetto extends to North Carolina; two native palms are found in South Carolina and four in Georgia. Louisiana, Texas, Arizona, and California, and their endemic species of palms, *Sabal louisiana*, *Inodres texana*, *Washingtonia arizonica*, and *Washingtonia filifera.* The palm flora of Florida, with more than a dozen native species, exceeds that of many countries crossed by the Equator, to say nothing of the coconuts in Florida, the dates in California, or the many ornamental palms which are suited to open-air cultivation.

The southern part of Florida, below Bradenton and Fort Pierce, has frost protection for tropical perennials and tree crops, especially near the coast. Most of the native flora of southern Florida is essentially tropical, like that of the West Indies. Mangoes, avocados, sapodillas, bananas, papayas, and coconuts, with many other palms and ornamental trees of distinctively tropical character, are in regular cultivation. Recently it has been learned that all of the more prominent rubber-producing trees, including the Hevea or Para rubber tree of Brazil, are able to thrive in southern Florida.

MAIZE OUR PREPONDERANT CROP

The native agriculture of America had an essential unity and continuity over both continents. From Canada in the north to Patagonia in the south maize was the principal human food. The local maize cultures were endlessly varied and differently combined with other crops, but maize was the chief reliance over most of the agricultural area. The native populations of each district in tropical America usually have several varieties of starch corns, some for early and some for late planting, also pop corns and sweet corns, which often are closely adapted to the local conditions.

Many varieties from tropical American countries have been brought to the United States and tested in different regions. Under

the new conditions the behavior of the variety may be completely changed and may become definitely abnormal. The large-grained Cuzco maize which grows in Peru as a rather small, productive plant 6 or 7 feet high, may grow in the United States to a height of 16 feet, and usually fails to mature any seed.

The general distribution of maize, as well as the local diversity of varieties and uses, affords further indications of the antiquity of agriculture in America, though several of the tropical root crops also are widely distributed. The general custom of grinding the maize kernels into paste after soaking in water may indicate a previous use of root crops, and especially of cassava. Cassava and other root crops have continued to be more important than maize in some of the humid lowlands, while in the very high altitudes in South America maize was supplemented by another series of root crops, which included the potato.

Small tribes of wandering, nonagricultural people survived in several parts of the New World, subsisting on natural products, or by hunting and fishing. Most of the natives of America planted crops and lived permanently in the same districts, though usually they did not farm continuously on the same land. A new clearing, or milpa, was cut and burned each year, planted for one or two seasons, and then left to grow up in " bush " for several years. In many districts the milpa system had given place to permanent cultivation, with a maize crop grown every year. The large-grained Cuzco maize was the principal crop that was grown in the specialized terrace agriculture of Peru. Likewise in Mexico and in Guatemala all of the ancient specialized systems of agriculture were applied to the production of maize.

Our preponderant cultivation of maize in the United States is in line with the traditions of ancient America. It is significant that in the United States the word " corn," the traditional name for the cereals of northern Europe, has been transferred in popular usage to the maize plant. Vastly more corn is planted than wheat. In 1929 there was a total of 98,000,000 acres devoted to corn as against 61,000,000 to wheat, the corn having an average yield of 26 bushels per acre and the wheat 13 bushels. The corn crop was more than three times the wheat crop in volume, and the value $2,000,000,000, more than double. Of cotton, 46,000,000 acres were planted, with a value of a billion and a quarter. Of potatoes 3,000,000 acres were grown, and of tobacco 2,000,000 acres.

FOOD HABITS DIFFICULT TO CHANGE

The growth of civilization that has occurred since the discovery of America would not have been possible if our European forefathers who settled in America had not found ready for their use a new series

of domesticated plants specially adapted to the local conditions in America which were often very different from the conditions that the colonists had known in Europe. The survival of the early colonists often depended acutely upon their readiness of adjustment to the new conditions, by learning how to use and grow the new crops.

Changes in food habits are notoriously difficult to make, as they generally are resisted by an immense and unconscious inertia. Under the compulsion of starvation the Pilgrim Fathers learned to use "Indian corn" in Massachusetts, but the French still insist that they would starve before eating it. That maize in various forms is relished and preferred to other grains by millions of Europeans who have settled in America would not induce the French to try it, even in wartime. Out of consideration for our allies, we were enjoined to eat maize and send wheat to France. We ate the maize and the French lost their chance of learning about it.

Our own use of maize as human food still is more limited than it might be, and probably more limited than it should be. On account of their better keeping qualities, "flint corn" and other hard-texture maize varieties are preferred in the United States for feeding animals, while for human consumption the soft "starch-corn" varieties are preferred. Many acceptable uses of maize current in the Tropics are not known in the United States. A native community in eastern Guatemala was supplied with hard maize from the United States in a famine season, but the imported grain made inferior tortillas and proved unwholesome.

VALUABLE COTTONS FROM MEXICO

The Upland cotton of the United States is identified in many text-books with an Asiatic species, *Gossypium herbaceum*, which in reality is not cultivated in America. An early reference is found to seed coming from the Levant, but from the plant characters it is certain that the varieties now grown commercially in the United States are not related to *Gossypium herbaceum*. Many Asiatic cottons have been planted experimentally in the United States and found to be much less productive than Upland varieties brought from tropical America.

The westward extension of cotton culture in the United States was facilitated by a new type of Upland cotton that appeared in Texas near the middle of the last century and probably came from Mexico, although no contemporary record of that fact has yet been found. Several varieties are recognized, as Mebane, Lone Star, and Rowden, which are known collectively as Texas Big-Boll cottons. In view of the rapid and continued increase of production in Texas and adjacent States, it may be estimated that the Texas Big-Boll cottons

probably are contributing at least half of the cotton that is produced in the United States. The crops that have been raised from this type of cotton would have aggregate values of many billions of dollars.

Other superior types of Upland cotton have come from Mexico and Guatemala in the present century. A cotton from the State of Durango in northern Mexico was grown successfully in many districts from southern Virginia to the irrigated valleys of southern California, and later was replaced by the Acala cotton, another Mexican variety which is well adapted to conditions of production over a large part of the American Cotton Belt. The native cottons of Guatemala and southern Mexico were studied for several seasons, beginning in 1902, by expeditions sent out by the United States Department of Agriculture to learn the possibilities of production in the presence of the boll weevil. In the summer of 1906 a cotton expedition crossed Guatemala from the east by way of Panzos, Purulha, Salama, Rabinal, Quiche, Totonicapan, Quezaltenango, and Huehuetenango, passed the Mexican border at Nenton, and traversed the State of Chiapas through Comitan, Ocosingo, and Salto de Agua. The existence of a superior type of cotton was recognized at Ocosingo, and in December of the same year another expedition to southern Mexico obtained a supply of seed at a town called Acala. A select stock bred from this seed has been grown extensively in recent years both in the United States and in Mexico. Most of the cotton of the irrigated valleys of the Southwestern States is of this Acala variety, and several advantages over the Texas Big-Boll cottons have been shown. The plants are of more erect habit, with more open foliage and greater resistance to adverse conditions. Larger crops of bolls can be set in shorter periods, and the fiber quality is superior. Eventually the Acala cotton may be used as extensively as the Texas Big-Boll cottons, if adequate supplies of pure seed can be established and maintained.

DOMESTICATION OF QUININE AND RUBBER

Two important domestications of South American plants were accomplished in the last century and may be credited to the scientific interest and initiative of one man—Sir Clements Markham. Foreseeing that the natural supplies of quinine and rubber would soon be inadequate, a systematic project for agricultural production of both commodities was undertaken and, after many vicissitudes, accomplished.

Markham and his assistants explored the forests of the eastern Andes in Peru and Ecuador and carried many kinds of Cinchona

trees to British India. Other experiments were made in the Dutch colonies, and the present commercial production of quinine is in Java. Following the introduction of the Cinchona into other parts of the world, botanists were sent to tropical America for seeds of the different rubber trees. Repeated efforts were made to obtain Hevea seeds from Brazil, and a large shipment reached England in the summer of 1876. The seedlings were forwarded promptly from the Kew Gardens to Ceylon and Singapore, but commercial planting did not begin till 1896, after a practical system of tapping had been discovered.

Sanitary control of malaria may have rendered the quinine domestication less significant than it was at first, but cultivated rubber has mounted rapidly to first-rank importance, both industrially and commercially. Not only have the producing districts in the British and Dutch colonies been transformed, but life in all civilized countries has been profoundly changed through the use of rubber in motor vehicles. The world was waiting to ride on rubber, and in a few years has become thoroughly addicted to the pleasure and convenience of rubber transportation. From an incidental status as a water-proofing material half a century ago, rubber has become the largest of our imports, and is recognized as an indispensable material of our present civilization. The imports of crude rubber into the United States during 1929 reached a total of 563,812 tons, with a value of approximately $240,966,780. Also motor vehicles are the largest of our exports, with the single exception of cotton.

OUR TROPICAL HERITAGE

Our acute dependence upon rubber may work a change in our traditional neglect of the tropical aspects of our national economy. Perhaps from excess of European patriotism we have refused to recognize our tropical status and interest in tropical possibilities. Little inclination has been shown in the past to consider that our agricultural production is on a different footing from that of European nations. They see us as a tropical country, but we refuse to consider ourselves in that capacity. Vast territories remain unutilized in our Southern and Southwestern States, awaiting more suitable crops which probably must come from the tropics. Temperate crops from Europe have been tried persistently since the first settlements were made, but are restricted to winter growth, while all of the crops that are grown in the summer are of tropical origin.

The industrial expansion of some of the European nations in the last century made them customers for wheat or other European

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crops that could be grown in the United States. The importance of home production of food in Europe, however, is now being recognized; one result of this will be a more careful consideration in America of a home market for food products. The time may soon come when we shall be willing to lay aside our remaining European prepossessions and face the necessity of making the most of our own country. With this viewpoint we shall cooperate more constructively with our American neighbors who are facing the same problems of utilizing tropical plants as the basis of economic and social advancement.

Neglect of such considerations is responsible for the present situation in the United States in regard to rubber, which undoubtedly could be produced as well or better in tropical America than in the East Indies. The history of the rubber development shows that much has depended on mere accident, through lack of interest. The accident whereby American rubber companies began with a different tree in Mexico resulted in discouragement at a critical stage when the East Indian plantations were beginning to be successful, so that valuable time has been lost. It was supposed that the world's need of rubber would soon be supplied, and this mistake is now being repeated.

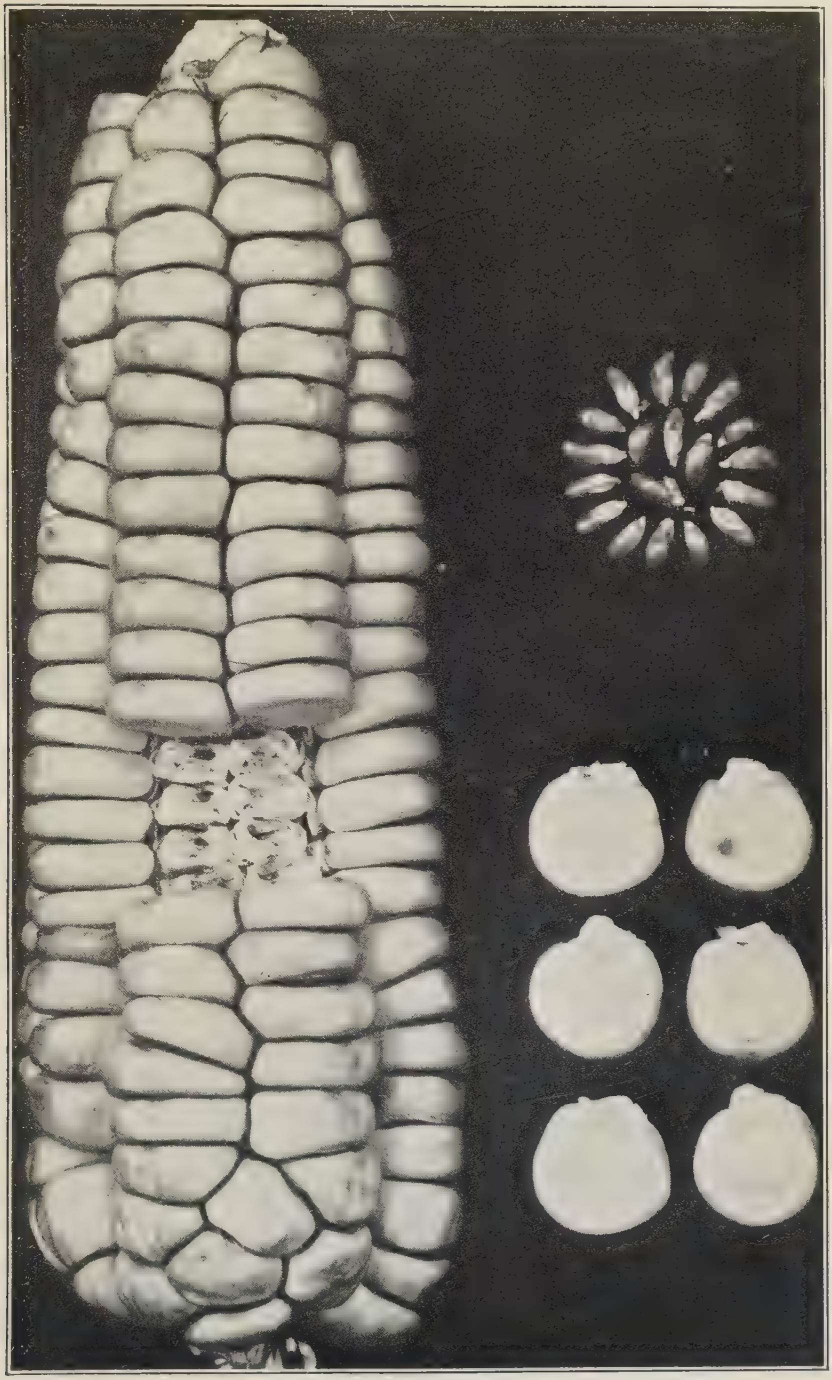
The discovery of a suitable tapping method for the Hevea tree in the East Indies also was accidental, except that the conditions for making such a discovery had been provided by the introduction of the tree. If the tapping method for Hevea had not been discovered, the cultivation of Castilla in Mexico and Central America would not have appeared as a complete failure. The rubber problems have been studied but little as yet, and practical ways of utilizing the Castilla tree or other rubber-producing plants may still be found. Mechanical extraction of rubber instead of the laborious tapping operation is the line of improvement to be expected, but different extraction processes, as well as different cultural methods, will probably have to be developed for each of the producing species.

The lesson is that in each country stocks of the different kinds of rubber trees or other useful plants should be available to furnish ample supplies of seed or propagating material for those who are interested in determining the possibilities of the new plants. The history of rubber affords many illustrations of the general requirement for progress in agriculture—namely, that the facts must be learned by actual experience and familiarity with the plants. There is no way to prophesy in advance that a plant will not grow in a new country, or that new uses will not be discovered. Nobody would have guessed that the Hevea tree would thrive in Florida or

that it would be less susceptible to cold than the Castilla tree, but such are the facts. Though the seedlings of the Hevea tree often require shade and wind protection, the range of possible cultivation is much wider than has been supposed and undoubtedly extends through the West Indies, Central America, and Mexico.

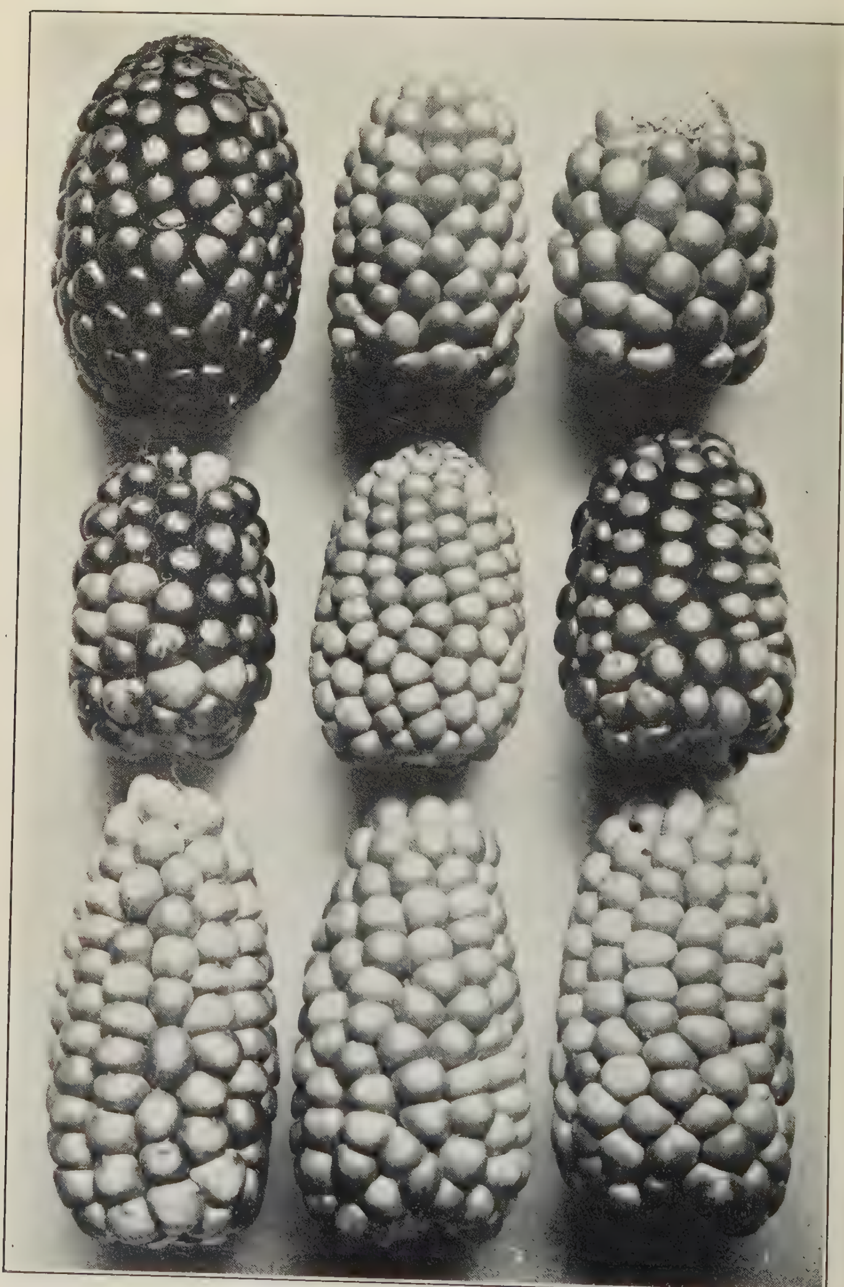
There is no apparent reason why the Hevea tree should not be a regular farm asset in many countries of tropical America. Only the lack of knowledge and the absence of the plant material can explain the absence of a rubber industry in tropical regions of farm production. Few crops can be handled with simpler tools or less machinery. The native farmers of the East Indies are now producing rubber to better advantage than the owners of large plantations. The use of motor transportation is extending in the Tropics, and the countries that can produce rubber should seek to supply their own needs.

The tropical world is rapidly becoming accessible to civilization, and even greater transformations may be expected than have occurred in temperate regions. Rubber gives us new powers that are producing magical changes in human life, in all civilized countries. A century ago the experiments of Hancock and Goodyear were being made, which opened the period of industrial invention and exploitation of rubber. Sixty years later the tropical forests of both hemispheres had been ravaged of their wild rubber. Only three decades have elapsed since plantation rubber began to be available in practical quantities. No other event in history has changed the world so rapidly as the domestication of the Brazilian rubber tree.



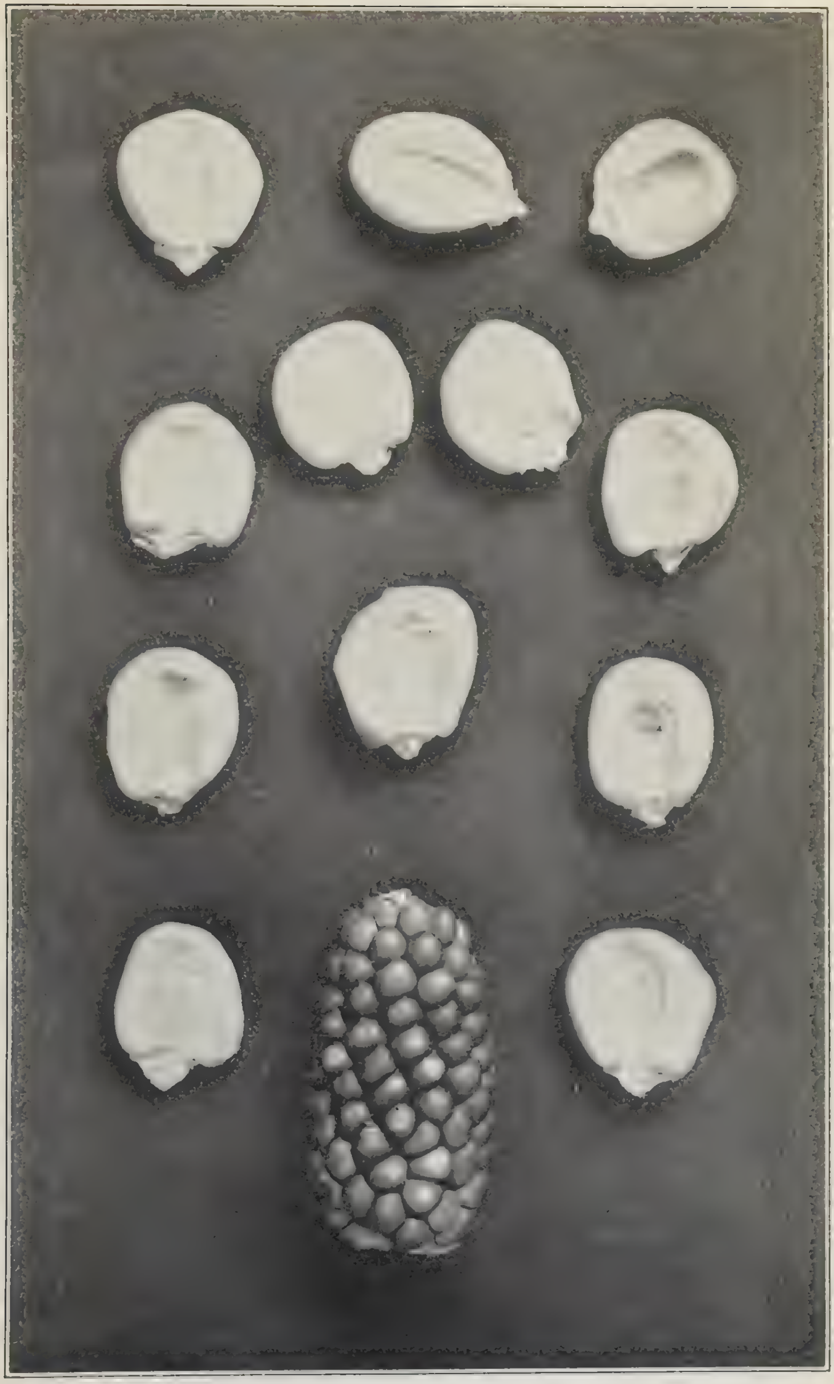
CUZCO, THE LARGE-KERNEL MAIZE OF PERU

In the middle farming zone of Peru, at elevations between 8,000 and 11,000 feet, the Cuzco type of maize is the principal crop. The large kernels, sometimes nearly an inch broad, are eaten one by one like grapes or chestnuts. Compared with rice pop corn. Natural size.



PIGMY MAIZE

Pigmy maize of the highest altitudes on the islands and slopes around Lake Titicaca, at an altitude of nearly 13,000 feet. Natural size.



PIGMY MAIZE

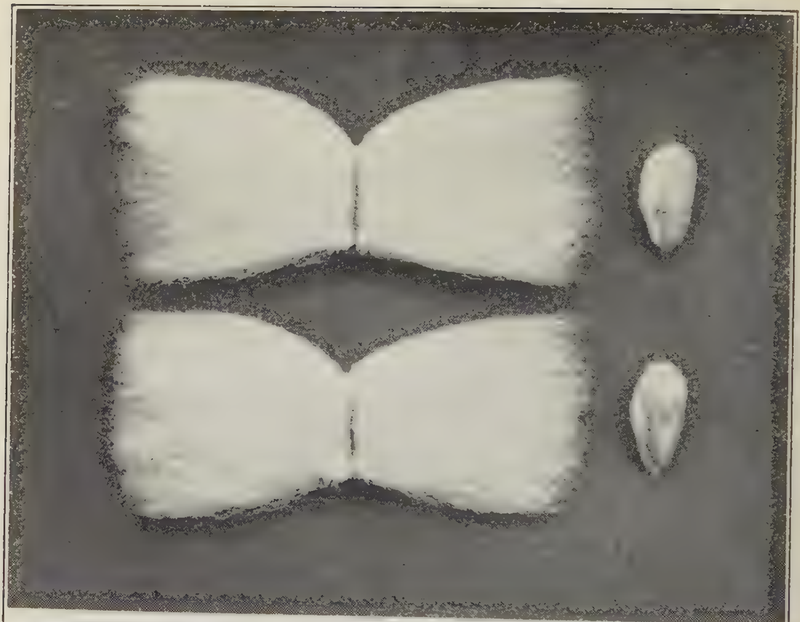
Ear of pigmy maize compared with kernels of Cuzco maize. Natural size.

A FIELD OF ACALA COTTON IN SOUTHERN CALIFORNIA

More than 1,000,000 acres are now planted to this variety, introduced into the United States from southern Mexico in 1907, in the irrigated valleys of the Southwest and in other Western States, returning hundreds of millions of dollars to American producers of this superior fiber.

ACALA COTTON

A mature plant showing abundant fruiting habit.



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1. Combed fiber and seeds of Acala cotton showing compact storm-proof bolls and uniform fiber. Natural size. 2. Open boll of Acala cotton. Natural size

TAPPING A RUBBER TREE

Tapping a hevea or para rubber tree in a small plantation on the north coast of Haiti. The trees have made normal growth and experiments have shown that the yields of rubber are comparable to those obtained in the plantations of the Orient.

SOME WILD FLOWERS FROM SWISS MEADOWS AND MOUNTAINS

By Casey A. Wood

[With 6 plates]

The north slopes of the Lake of Lucerne form an important area of the Four Forest Cantons. There nature seems to have arranged them especially for an exuberant growth of Alpine and sub-Alpine wild flowers. This charming locality with its southern exposure is protected from cold winds by the surrounding hills, while rainfall and sunshine are justly proportioned to stimulate the growth of foliage and bloom from the meadow flowers on the lake margins to the pines and snow plants of the Rigi-Kulm, 6,000 feet above it.

After a winter in Rome we arrived at Vitznau, 10 miles from Lucerne, at the end of April to witness the unfolding of a second semitropical spring. The Park Hotel, surrounded by what is virtually a small botanical garden of 5 acres, furnished the trees and plants—oleanders, magnolias, wisterias, roses, forsythias, weigelias, hydrangeas, judas trees, spiraeas, azaleas, flowering chestnuts, etc.—that had passed their bloom when we left the Eternal City, but once more opened in all their belated charm and glory to give us a hospitable Swiss greeting.

It was not, however, to the official gardener and his assistants that we turned for botanical information, but to the lovely hills and high mountains that walled us in on the north and spread before us in seductive vistas—snow-capped some of them, verdure-clad all of them—to the far south. We organized walking expeditions, steamer excursions, and motor trips to explore this naturalist's paradise. Even the feeblest climber of our party finally did a 6-mile hike over the hills and far away to a Swiss hamlet near the snows, passing through indescribably beautiful Alpine meadows and green pastures carpeted with wild flowers. On these walking tours (and Baedecker was undoubtedly right when he said that the only way really to see a country is to tramp through it) we had ample opportunity to admire the cleanly, effective, and artistic fashion in which the Swiss people have regulated, adapted, and improved even

the smallest village and its surroundings with an eye to their chief source of income—the tourist traffic. Their hotels are the best in the world; even off the beaten path of travel one is sure to find a warm welcome in some well kept, clean, and reasonably cheap inn or pension.

The abundant rainfall of the Forest Cantons and the melting snows not only supply the moisture needed for a luxuriant vegetation, but they furnish in the shape of waterfalls delightful attractions to the Alpine scenery. The falls vary in size from the tiny but decorative tricklings that are wholly dependent for existence on intermittent rains to the more or less permanent cataracts largely fed by the eternal snows. More than that, water power is a valuable asset. One of its numberless local uses is its cheap and universal employment in electrically lighting the whole country, the surplus power being sold to neighboring countries.

One must not forget the birds in this brief account of the glories of the Forest Cantonal scenery. The notes of the cuckoo, the blackbird, the song sparrow, the nightingale, and other songsters are heard in this delectable land. One might, on a tramp over sub-Alpine hills and valleys, recall Marlowe's lines:

> Shallow rivers to whose falls
> Melodious birds sing madrigals.

Over a hundred years ago Prince Charles Lucien Bonaparte, one of our foremost authorities on American ornithology, wrote for an Italian journal a comparative account [1] of the birds of Rome and Philadelphia, in which he showed that although many of the 247 species observed in the former metropolis differ in some respects from 281 avian visitors to the American city, there are in numerous instances few external characters to distinguish the Old World from the New World birds. Much the same experience has characterized the present writer's desultory adventures with Alpine flora and fauna, since the differences between the flowers and birds of, let us say, California and the Forest Cantons, are not, after all, so very great.

In the present paper it is proposed to emphasize the differences and similarities of some Swiss species of wild flowers not unfamiliar to Americans, and it may be said at the outset that one suffers from an *embarras de richesse* in such a study because, as many botanical authorities have noted, no country in the world can produce in a similar limited area as many species of indigenous plants as the two cantons of Schwyz and Lucerne. Stuart Thompson, for example, has estimated that, excluding varieties and subspecies, there

[1] Specchio comparativo della ornitologia di Roma e di Filadelfia. Nuova Giornale dei Letterati, 1827.

are at least 2,540 species of wild ferns and flowering plants in Switzerland, and it is not claiming too much for the mountains and valleys of the Forest Cantons to say that they possess about 2,000 indigenous species.

The greatest variety and most brilliant display of these blooms are found from April to November in the Swiss meadows and pastures, a cultivated acre or two wrested here and there from the forest and rocks of a stern and mountainous land. It is when and where the peasant farmer waits for the development of his biennial crops of grass, hay, and other fodder—that is to say, anywhere from the margin of the lake to the pines that grow almost to the line of perpetual snow—that these small but brilliantly green oases of cultivated land are to be searched for wild flowers. A mountain meadow in May is a joy lost to the traveler who sees only the more widely advertised and monumental sights of Switzerland.

Hoffmann strikes the correct note when he remarks that the serious student of Swiss wild flowers soon realizes that besides the classic *Alpenrosen* and *Edelweiss* there are many other species of wild flowers "that find their home only in the Swiss mountains, where their blossoms sometimes stand so close together as practically to form a covering for pastures, meadows, and rocks. Such floral carpets, quite characteristic of the landscape, fascinate by their brilliant coloring even the eyes of those who take but a moderate interest in the more scattered flora of their own native land." (Pl. 1.)

Imagine, then, a relatively small patch of cultivated hillside 1,000 to 8,000 feet above sea level on which, throughout most of the spring and summer, grow blooming masses of centaurea (especially *C. montana*), vetches, rampion (*Phyteuma spicatum* and *P. orbiculare*, both purple and white), eglantine, gentian (4 varieties), wild geranium (4 varieties near Vitznau), lilies, violas, columbine, saxifrage, blue bells, globe flowers, pinks (*Dianthus superbus*), cyclamen, eyebright, nettles, fragrant cow-parsley, shasta-like daisies (and their first cousins, the Alpine chrysanthemums), arnica, primroses, monkshood, Alpine meadow rue, speedwell (interspersed with many-hued clovers and ornamental grasses), scabiosa, catchfly (*Silene inflata*) both mauve and white-flowered forms, Alpine balsam (*Erinus alpinus*), groundsel (*Senecio doronicum*), soapwort (*Saponaria ocymoides*), milkwort (*Polygala alpestris*), sainfoin (*Onobrychis montana*), cotton grass (*Eriophorum angustifolium*), plantains, St. Bernard's lily (*Anthericum liliago*), blue chicory (rarely the flowers are white), yellow and white ranunculus, mustard, pink bistort, hawkweed, alpenrosen (*Rhododendron*), and dozens of other flowering plants of which our limited space does not permit even the bare mention.

Perhaps also, especially during the first weeks of spring, one may be lucky enough to come in the higher hills upon a field whose center is occupied by a melting snowbank or ice layer, a hundred or more feet across, whose periphery is aglow with flourishing groups of soldanella, oxlip, silver thistle, hepatica, crocuses, blue snow gentians, primroses (among them *Primula auricula*), the Mediterranean heath (*Erica carnea*), butterwort (*Pinguicula alpina*), spring columbine, violets, for-get-me-not (*Myosotis alpestris*), buttercups (*Ranunculus glacialis*), and other early flowers, mixed with still earlier grasses and small shrubs. The present writer has on several occasions picked bunches of many-colored flowers on the margins of a névé whose ice-cold water warmed in the sun became a fit stimulant and food solvent for the surrounding vegetation.

In the protected Alpine woods a somewhat different flower exhibit is held. Here, for example, most of the Swiss orchids are found, more than 20 species in the Forest Cantons, a remarkable showing when contrasted with the few species found in the whole of North America. Then again, harebells, wood geranium, rockrose (*Helianthemum vulgare*), St. Johnswort (*Hypericum maculatum*), cinquefoils (*Potentilla aurea* and *P. argentea*), *Prenanthes purpurea*, chickweed (*Cerastium arvense*), willow-herb (*Epilobrium angustifolium*), *Moehringia muscosa*, *Digitalis ambigua*, valerian (*Valeriana trypteris*), *adenostyles alpina*, several mints (among them *Mentha sylvestris*), Turkscap lily (*Lilium martagon*), broom (*Genista tinctoria*), rockcress (*Arabis alpina*), clematis, honeysuckle, chicory, woodbine, cowslips, and many other shade and water loving plants flourish along the banks of the mountain rills, together with a multitude of lovely ferns, mosses, and rock plants.

Speaking of the last named, the geologic formations of the Swiss mountains, especially the glacial and other sedimentary rocks, form admirable backgrounds for rock gardens, and here rather than in artificial creations, however extensive and well kept, are to be found the most wonderful of these peculiarly attractive examples of floriculture. Scattered over and almost covering some of the " puddingstone " areas (glacial moraines) of the Forest Cantons may be seen many a flourishing wild " garden " that puts to shame both in variety and quantity of bloom the vaunted and carefully cultivated imitations to be found in our botanical parks.

From the foregoing will be readily imagined the difficulty attendant upon an attempt to describe in anything like detail the hundreds of wild species that flourish in the meadows, pastures, forests, valleys, and rugged mountains of the cantons bordering on the Lake of Lucerne. Even when one confines oneself, as in this short paper, to the indigenous flowers of the two cantons, Schwyz

and Lucerne, an apology is due to the reader for this scant treatment of the theme. However, the following are a few of the most attractive plants the writer has seen in his rambles about the Vierwaldstättersee.

Edelweiss, the "noble white" or, to give its high-sounding but cacophonic systematic name, *Gnaphalium leontopodium*, is popularly supposed to be a denizen of only the high Alps, but although it is now found only in wild and secluded mountain areas, usually about 10,000 feet above sea level, this is in part the result of the ruthless fashion in which it has been plucked by the root for the past century by careless or unscrupulous tourists and flower sellers. Throughout Switzerland, as a protection against complete extinction of this plant, the taking of the root is forbidden by law. Moreover, as a further preventive of the eradication of this pretty plant, its cultivation at low levels as a garden flower is almost universal throughout the Confederation. For many years the edelweiss flourished in a famous Alpine garden conducted by Herr Stierlin, a well-known hotel proprietor, on the Rigi-Scheidegg. Since the World War this garden has, unfortunately, been abandoned. However, the flowers are successfully cultivated in a private garden at Gersau, on the Lake of Lucerne, Canton Schwyz, where the size of the plant has much increased and the colors of the flowers have greatly improved under domestic care. It is now well understood that the plants may be raised from seed, and Stuart Thompson notes that it has grown well and flowered profusely on the top of a house in the center of London (pl. 3).

Taking it all in all, the most interesting flower that blooms in Alpine heights is the blue *Soldanella alpina* L. There are four species of this genus, at least one variety of which, the blue moonwort, has been grown at low levels and naturalized in foreign gardens. We are indebted to that charming writer, Grant Allen, for one of the best descriptions of this wonderful species and of its ice-boring qualities. The appearance of the crocus and other early flowering plants as they push their way through the snow is always a source of joy and wonder to the lover of spring flowers, but the activities of a plant that actually drills a passage to air and sunshine through several inches of solid ice is not observed by every naturalist.

In the autumn the soldanella develops thick, leathery leaves, well provided with fuel (starch, protoplasm) for the coming winter. These lie flat upon the ground (see fig. 1) expectant of the snow and ice sheet that may cover them to a depth of several feet. When the spring arrives and the hot sun melts most of the snow and some

of the ice, water trickles down to the rootlets and arouses growth in the sleeping plant. Internal combustion ensues within the floral

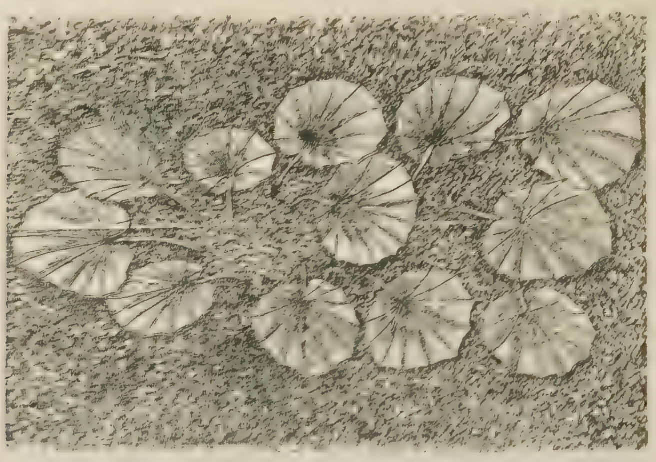

FIGURE 1.—The autumn leaves of *Soldanella alpina*—the plant that melts ice and snow

tissues. The resulting heat melts the ice about the uprising flower buds, and the stem pushes its way upward. More water flows to the roots; increased activity is induced, and finally, after several setbacks or "regelations"—as Tyndall calls them—the plant, especially if its race is run along the margin of the ice sheet, soon tunnels a passage to the air and sunshine.

FIGURE 2.—Flower-stalk of soldanella making a passage to the surface of an Alpine ice sheet. (After Grant Allen.)

So long as the heat given off from the growing stem and buds is sufficient to prevent actual solid freezing of the parts, the soldanella is indifferent to the surrounding ice-cold temperature; it undergoes the usual transformations, is fertilized by early bees, and forms many hundreds of wonderful blue flower groups that crowd the margins of the névé, some of which look for all the world as if they were beds of bloom actually rooted in and growing out of a thick layer of transparent ice.

If one now examines the leaves of the plant it will be noticed that they are no longer thick and fleshy, but are thin and papery;

they have yielded up their carbon compounds as fuel to melt a tunnel in the ice, and the production of the buds and blossoms on the flower stem above the ice mantle. The illustrations (figs. 1, 2, and 3) attempt to show the progress of the flower stalk from the autumn leaf beds to the full development of the flowering plant the following spring. (See also pl. 2, fig. 1.)

The Swiss *Orchidaceae* have already been mentioned, but their number and the beauty of their blooms call for special reference. Many have fragrant flowers, beautifully colored, with fantastically shaped separate flowers or flowerlets borne on long spikes. They

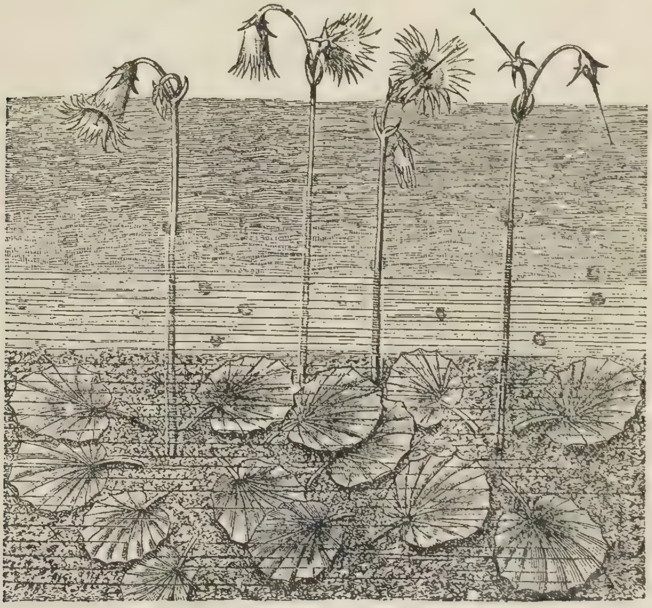

FIGURE 3.—Soldanella flowers that have by their own heat tunneled a passage to light and air through the overlying sheet of ice. (After Grant Allen.)

are commonly found at middle and high altitudes. The great majority of Alpine orchids are also native elsewhere—in Europe, Asia, and America.

These highly valued plants are generally thought to be difficult of cultivation, and it is true that some of them do not readily bloom after transplantation. All of them require a deep planting, many in a limestone soil mixed with peat. They should never be moved except in the late autumn after flowering and plant growth have ceased. A few of the most interesting are as follows:

The green-winged orchid (*Orchis morio*) has four color varieties—mauve, purple, pink, and white. They have erect stems 6 to 8 inches high, and the flowers are disposed in a handsome, loosely

arranged spike, the sepals curiously arched like a helmet. The *morio* is among the most attractive of the native orchids. It is well known also as an English species, and at least six others of this attractive genus are found in the British Isles.

Of the genus *Gymnadenia*, the species *odoratissima*, 4 to 10 inches high, presents mauve flowers on a long spike that have a pleasant odor.

Nigritella angustifolia is found throughout Europe. It is 3 to 8 inches in height and carries its small dark carmine flowers as a crowded spike. It is found in upland Swiss pastures from 5,000 to 8,000 feet above sea level. It is called the vanilla orchid, and has a pronounced odor of that bean.

Cypripedium is a genus well known to Americans as ladyslipper. The Swiss species (*C. calceolus*) closely resembles our own plants. It is found at low levels, not being strictly Alpine. As is well known, species of this beautiful genus are found all over the world (pl. 6).

The charming butterfly orchids (*Platanthera bifolia* and *chlorantha*) are also widely distributed. Their stems are 12 to 30 inches high; the flowers are white to whitish green, arising loosely in a 3 to 6 inch spike, and they are both fragrant.

An orchid that grows on mossy banks and mountain pastures up to 4,000 feet is *Herminium monorchis*, called from its pronounced odor, the musk orchid. It has a pretty "flower," a slender spike with numerous small, yellow-green blooms.

A curious sub-Alpine plant, found in shady woods up to 4,500 feet—at Engelberg, for example—is the birdnest orchid (*Neottia nidus-avis L.*) The stem is 12 inches high, with loose scales taking the place of leaves. Two or three pale-brown flowers are borne on a 4-inch spike. Its name derives from the dense mass of fibers constituting the root system.

A very pretty orchid, also found throughout Europe, is *Limodorum abortivum*. The whole plant (12 to 24 inches high, including the large flowers) is violet in color. It is commonly found in pine woods.

The smallest European orchid is very rarely seen above Lucerne. This is the bog orchid (*Malaxis paludosa*). The flowers are insignificant, and the plant is difficult to find in the peat bogs where it grows.

A very handsome genus with many species, found in the Forest Cantons, is *Cephalanthera*. *C. rubra* (red helleborine) may grow to a height of 20 inches, supporting its bright pink flowers in a loose spike. This fine plant prefers the shelter of woods and thickets, growing in a limestone soil. A pure white variety (or perhaps dis-

tinct species) closely resembles the foregoing. Another Swiss species of this genus is the charming *C. latifolia*, 12 to 20 inches high, whose flowers are cream colored and are found in June on sub-Alpine wooded hills.

Finally, to mention another orchid genus represented in North America, is *Epipactis*. The 10 Swiss species are rather tall plants with leafy stems bearing brown, purple, or greenish-white flowers, occasionally tinged with red, in a loose raceme. In *E. palustris* the white, green, orange, and purple flowers are large and very beautiful. The smooth stem is about a foot high, and the plant prefers marshes and watered meadows reaching 4,000 feet above the sea.

The crocus—that harbinger of spring—is represented in Swiss upland pastures and snow fields (to 7,000 feet) by the very pretty *C. vernus*. The white or violet flowers open before or with the coming of the grasslike leaves, and sometimes appear (April to June, according to elevation and situation) surrounded by the, as yet, unmelted snow.

Seven other wild species of the iris family are known in Switzerland, all capable of domestication in gardens and at low levels.

Primula elatior, the oxlip, resembles *P. veris*, the familiar cowslip, only it is more erect than the latter, has larger and longer leaves, and its many-flowered umbel is straw-colored and larger than the cowslip bloom. It is not scented. This early plant is common from April to July in meadows, woods, and pastures up to 7,000 feet (pl. 2, fig. 2).

Anemone sulphurea, with a stem 6 to 18 inches high, bearing a large, solitary yellow-white flower (pl. 4), is by some regarded as a variety of *A. alpina*, which it closely resembles, although the latter has a white flower tinged with blue below. Both have ternate, bipinnatifid root-leaves with deeply cut segments. These species affect pastures and rough ground on Alpine slopes, and bloom from May to July.

Monkshood (*Aconitum napellus*): There are several Swiss aconites, but this species is the commonest about the Vierwaldstättersee.

It has a striking resemblance to the delphiniums of our gardens and is equally capable of cultivation and improvement in color and size. Perhaps its violent poisonous qualities act somewhat as a deterrent in that direction. In our own American gardens it appears as a beautiful plant with dark violet (occasionally purple, light blue, or white) flowers borne in a simple, cylindrical raceme. The plant loves upland woods, damp meadows, the margins of a small stream, or the vicinity of a herdsman's hut, in return for whose shade it provides the decoration of its charming flowers. It blooms from June to August between 3,000 and 8,000 feet above sea level (pl. 5).

That immense family Ranunculaceae is so largely represented about the Lake of Lucerne that all the allotted space for this paper might easily be filled with the briefest sketch of its pretty Swiss species. One of these is *Clematis alpina*, that fine creeping shrub with large, solitary violet flowers borne on long stalks. It loves stony, wooded uplands 2,000 to 7,000 feet above the sea. The flowers persist for a long time in shady nooks from June to August, and the plant has a pleasing habit of covering the rugged limestone rocks among which it grows with its present leaves and last year's tendrils.

Of the numerous Swiss anemones, *A. hepatica*, as described in Flemwell's "Alpine Flowers and Gardens," reminds one of our own spring flower, the earliest of the year. "As the snow recedes," says he, " the brown bed of the pine forests (around Bex in the Rhone valley) is decked with myriads of Hepatica; their thick clusters of mauve-blue flowers, relieved here and there by the rarer forms of white and rose, . . . creating a veritable laughing fairyland where, usually, all is sedate if not gloomy."

The gentians: The Forest Cantons have their proper share of this world family. There are fully 20 species of the genus found in Switzerland, most of them about the Lake of Lucerne. The flowers of the gentians are usually a deep blue, but in some species are mauve, yellow, purple, or nearly white. Though they are generally solitary on the flower stalk, yet they also occur in terminal cymes. Both corolla and calyx are distinctly tubular and often angled. The accompanying figure (pl. 3) shows *Gentiana acaulis*, the stemless gentian. Although in this species the flower stem is very short, it is not absent, as Linnaeus pointed out in his description of the type specimen now in the Linnaean Herbarium at Burlington House, London. The corolla is 1 to 1½ inches long and is deep blue, with greenish (rarely) white or mauve streaks. This beautiful plant grows in grassy Alpine pastures and meadows up to 8,500 feet. Its association with the edelweiss in the illustration (pl. 3) is carried out in bouquets sold to tourists where the one flower is a foil to the other—both supposed to have been gathered well up to the snow line.

Gentiana nivalis must also be mentioned, as it is the species that from June to September shows its small blue or mauve flowers at great elevations (5,000 to 10,000 feet) and opens them only when the sun shines brightly. It is a small plant, 1 to 6 inches high.

Fringed gentian (*Gentiana ciliata*): This beautiful species has been justly celebrated in verse and prose. It is a hardy biennial or perennial, with a stem 3 to 10 inches high, carrying large, handsome, pale (electric) blue flowers with a strongly divided corolla, whose margins are strongly " fringed " or ciliated. The flowers are often solitary, or there may be several to the stalk. This lovely plant

blooms from August to October, being distinctly an autumnal species. It prefers Alpine pastures and hillsides up to 8,000 feet, and is especially fond of shade and a soil of limestone detritus.

Few subjects in local natural history have produced a more extensive literature, in English, French, and German, both popular and systematic, than Alpine plant life. Both the tourist and the amateur botanist are confronted by a small library of works when either proposes seriously to pursue this fascinating study. The English reader will, however, find that two well-illustrated volumes of H. Stuart Thompson cover the ground fairly well. These are "Alpine Plants of Europe," 287 pp., 64 colored plates, London, 1911; and "Sub-Alpine Plants; or Flowers of the Swiss Woods and Meadows," 325 pp., 33 colored plates, London, 1912.

To these might be added an excellent English translation of a book by Correvon and Robert, "The Alpine Flora," 436 pp., 180 water colors, Geneva; and another but smaller work by L. and C. Schröter, "Coloured Vade-Mecum to the Alpine Flora," 217 colored and plain drawings, 21st edition, Zurich.

In the preparation of this paper the writer has had the assistance of Miss Marjorie Fyfe, Mrs. Howard Wilson, and Mrs. Constance Domvile. These ladies spent many days (from April to September, 1930) exploring the wooded heights, mountain meadows, hilly slopes, and natural rock gardens of Lucerne and Schwyz, searching for botanical specimens. The result is an amateur herbarium showing several hundred species of wild flowers, which has been a decided help toward an appreciation of the abundant flora of at least two delectable Forest Cantons.

AN ALPINE MEADOW CARPETED MOSTLY WITH THE YELLOW GLOBE FLOWER
(TROLLIUS EUROPAEUS)

1. GROUP OF BLUE SOLDANELLAS FREE OF SURROUNDING ICE AND SNOW

2. THE SWISS OXLIP (PRIMULA ELATIOR) GROWING NEAR A STREAM IN AN UPLAND PASTURE

EDELWEISS (LEONTOPODIUM ALPINUM) AND GENTIAN (GENTIANA ACAULIS)

SWISS YELLOW ANEMONE (ANEMONE SULPHUREA)

WILD MONKSHOOD (ACONITUM NAPELLUS) FROM A SWISS UPLAND POND

A GROUP OF LADY'S-SLIPPER (CYPRIPEDIUM CALCEOLUS) IN AN ALPINE THICKET

THE ANTIQUITY OF CIVILIZED MAN[1]

By A. H. Sayce

Many years ago Professor Huxley remarked to me: "If you wish to clarify your ideas, you can not do better than give a lecture." The remark made a deep impression on me, and the truth of it has been abundantly verified by my subsequent experience. Our conclusions are not infrequently derived from premises which have been forgotten or never fully thought out. We are apt to assume that facts or ideas familiar to ourselves are equally well known to the rest of the world, and the attempt to explain them to others makes us realize how far this often is from the case. Each of us lives to a large extent in an intellectual world of his own, and it is not until we have to make it clear to others that we discover how much of it is overshadowed or rendered misty by familiarity.

It is not, however, the individual only whose ideas need clarifying. Science, as we know, is progressive, and the successive stages in its progress are each marked by a general atmosphere of its own. Assumptions are made upon evidence which is undefined or ill defined, but which is taken for granted as was animism by primitive man. I am old enough to remember the time when layman and scholar alike assumed that the appearance of man upon this globe was a thing of yesterday. The geologists, it is true, had already begun to accustom the more intelligent portion of the public to the conception of a long period of existence for the earth itself, but so far as man was concerned, his history was still limited by the dates in the margins of our Bibles. Even to-day the old idea of his recent appearance still prevails in quarters where we should least expect to find it and so-called critical historians still occupy themselves in endeavoring to reduce the dates of his earlier history. In fact, his extremely modern character had become so fundamental a part of our stock of beliefs that it is difficult to realize with what a shock the announcement came upon the ordinary educated world when as a schoolboy I listened to Sir Charles Lyell's famous address to the British Asso-

[1] The Huxley Memorial Lecture for 1930. Reprinted by permission from the Journal of the Royal Anthropological Institute of Great Britain and Ireland, vol. 60, July to December, 1930.

ciation at Bath in 1864. To a generation which had been brought up to believe that in 4004 B. C., or thereabouts, the world was being created, the idea that man himself went back to some 100,000 years ago was both incredible and inconceivable.

But it was uncivilized man, not *homo sapiens*, as he is called today, of whom this was postulated, and between *homo sapiens* and his predecessor or predecessors the scientist still inserts a period of untold centuries. It is true that the Tasmanian with his paleolithic implements and mathematical deficiencies still survived into our own time; but he possessed a language and could even cook his food and make clay vessels. It is also true that Cromagnon man had a skill which rivalled that of the modern European and has left us works of art which, considering the conditions under which they were produced, place him on the highest stage of artistic ability. But he, too, possessed speech and belonged to the later and not to the older Paleolithic age of Europe. After all, it has been assumed, his distance in time from us has not been so great when measured with that which separates us from Chellean and still more Eolithic man.

Recent discoveries, however, in Southern and Eastern Africa have been disturbing. I learn from Sir Arthur Keith and L. S. B. Leakey that *homo sapiens* already appears in the Rift Valley of Kenya at the beginning of the second major pluvial period which may roughly correspond with the two last glacial epochs of Europe (the Riss and Würm). He had already invented pottery before the closing stages of that period, so that by the next wet period or the first post-pluvial wet phases of it he had developed a class of pottery of really good character. The Mousterian type of culture in Kenya existed contemporaneously with the Aurignacian throughout the second major pluvial epoch, gradually developing as time progressed. *Homo sapiens*, therefore, with his art of pottery making and the use of fire which it implies, is thus pushed back to an age which we have hitherto associated with his semisimian predecessors.

Man, that is to say, civilized man, or man in the true sense of the word, must therefore have existed untold centuries ago. He already possessed the potentiality of speech; we may argue from his artistic skill and products that that potentiality had been already translated into fact. The greatest invention ever made by him had already been made. That language was an invention we know; every child born into the world has to learn it. And language exists irrespective of race. Wherever we find man, however low he may be in the scale of humanity, he is possessed of language. The further we go back in his history, the more multitudinous are the languages which he has spoken. The tendency of an advance in civilization is to

minimize their number and merge the languages of the smaller tribes or nations into that of the dominant power. The Roman Empire was a case in point. And what is true of the multiplicity of languages is true also of their character. Simplicity is a sign of age and progress; the most intricate and complex grammar is usually to be found among peoples of a low type. If we could transport ourselves back to the Aurignacian artists of France and the draughtsmen of the extinct animals of Africa, I fancy we should find a multiplicity of dialects and languages and a corresponding complexity of grammar.

What all this indicates is obvious. Civilized man—and man who had invented language and was a first-class artist, was already civilized man—is exceedingly old; his antiquity can not be measured by centuries or even by millennia. This much is the teaching of prehistoric archeology. Let us now turn to archeology in the more restricted sense of the name and see what it can tell us.

At the outset we are met by the historians on what may be termed the "lower margin of archeology," whose sphere of work begins where that of the archeologist ends. The historian has to deal with literary records and his outlook, therefore, is subjective rather than objective. The interpretation, and, still more, the valuation of them, is a purely subjective matter dependent on his own judgment, prejudices, and knowledge. Words, as we know, can be twisted in manifold ways and it does not follow that what the original writer meant by them is what his later critic believes them to signify. Where the documents belong to a distant past, more especially if that past belongs to a different world and civilization from his own, the conclusions of the critic are apt to be mistaken. They represent his own surroundings and not those of the past.

The more distant the past and the more scanty the literary remains which belong to it the more doubtful and open to suspicion must the verdict of the historian be. His interpretation of the evidence must be purely subjective and colored by the assumptions and prejudices of his own time. Before we can accept it, it must be tested by the objective facts of archeology.

One of the leading obsessions of the historian has been the belief in the recent evolution of civilization and the shortness of the period during which it has endured. The obsession, as I have already noted, is derived from medieval tradition—civilization was believed to have been coeval with the creation of man, and man, like the rest of the universe, to have been in existence only about 6,000 years. The science of geology in its early days had hardly penetrated into the ranks of the historical scholars, and the famous presidential address of Sir Charles Lyell on the Antiquity of Man, to which I

have alluded at the beginning of my lecture, fell like a bombshell upon an unbelieving world. I well remember the sensation it created and the numerous criticisms and "replies" which it called forth. But the historian comforted himself with the assurance that the "man" of the geologist was not the civilized and literary man with whom he had to deal, but merely a superior sort of ape. Civilized man was the man who had left books behind him which could be criticized and fully explained by the modern writer of books.

Medieval tradition had left yet another belief behind it which coexisted with the belief in the brief duration of humanity and the universe. It was the belief in the decline instead of the progress of civilization and culture. The belief had been handed down from the classical world which had looked back with regret upon "a golden age," and it had been fostered by the manifest relapse into barbarism which characterized medieval Europe. Travelers in Egypt brought back stories of the marvelous monuments of a remote past which were still to be found there; Roman culture had been inferior to that of Greece, and the civilization of the Roman Empire had been succeeded by the Dark Ages. Civilized man, in short, had had but a brief existence, and it was accordingly evident that documents which ascribed to him an earlier date were unworthy of credence. It needed but little ingenuity on the part of the critic to resolve the earlier narratives given in them into myths and inventions and to lay down that literature in the true sense of the term did not exist before the seventh century B. C. The heroes of the old legends became solar myths and the "ancient empires of the East" were stripped of their antiquity.

A new era has dawned upon us. The scientific method, aided by the spade, has opened up a new world and furnished us with facts instead of theories. And the result is that the same story, as that which geology had to tell us, is being retold. The age of civilized man must be pushed back through the centuries like the age of uncivilized man. Catastrophic theories are no more applicable to him than they are to the human being who had not yet invented language or learned how to cook his food. Art and culture did not spring suddenly into existence like Athena from the head of Zeus.

The last hundred years have, indeed, unfolded to us a new world, that of the civilized past. It is difficult for me to realize to-day how little we knew of it in the days when I was a boy. The inscriptions of Egypt and Assyria, it is true, were beginning to be deciphered, but the historian still looked upon their interpretation with suspicion, and some, like Sir George Cornewall Lewis, rejected it altogether. So far as the Ægean was concerned, its history began with the Ionic colonization of the Asiatic coast, and the "Homeric

age" was synonymous with the mythological period. When listening to a lecture last year by an eminent classical scholar upon the successive naval hegemonies in the eastern basin of the Mediterranean, to each of which he assigned a precise date, I could not but think of the contrast with the orthodox attitude of mind in my younger days toward what were then considered the inventions of a later literature. It was then grudgingly admitted that libraries might have existed in Greece in the fifth century before our era, but even so, they would not have been libraries in our modern sense of the word, in which the various branches of literature are represented and students come to study them.

It is true that there were some old-fashioned people who still believed that the earlier books of the Old Testament belonged to their traditional date and that some of them were written by Moses himself. But this was the exception to the rule, so much the exception, indeed, that a special revelation from above was called in to explain it. And we of the younger generation, trained in the critical methods of Germany, were unable to accept the dogma; it rested only on unproved assertions and was contradicted by the character of the documents themselves. If there were no libraries and literature in early Greece, still less probable was it that they should have been found in the Hebrew world.

And where there was no literature to hand down the facts of history it was assumed to be unlikely that history could exist. Human memory is notoriously defective and forgetful and the phantoms of imagination take the place of sober facts. Instead of history we should expect to have folklore and fairy tales. More especially would this be the case in a literary community, such as that of modern Europe, to which the critics belonged; here the memory had been weakened by centuries of literary tradition and the critics found it difficult to believe the stories that were told of Indian scholars who had handed down the Rig-Veda orally, or of Polynesians who professed to remember the names and deeds of former chieftains for numberless generations. The argument seemed unassailable; without books and libraries there can be no history, and since books and libraries could not be traced back beyond a few centuries before our era, the earlier so-called history of the world, it was clear, must be little more than myth. And from this it further followed that where we have no history we can not assume that civilized man existed or could have existed for any considerable period of time.

The historian is still largely under the spell of these prepossessions and beliefs. The purely archeological record naturally leaves him untouched. He is content to let the archeologist discourse about stone and bronze ages and assign to them long periods of time so

long as there is no question of exact dating or of interference with the antiquity which he would assign to his own protégé, literary man. Here he believes he can count the generations, and the oftener he counts them the fewer they become.

But archeological science, hand in hand with the decipherment of the languages and records of the past, has come with a rude shock, and the most recent discoveries have been more than usually subversive. Civilized man in the fullest sense of the word is immeasurably old. His history forms no exception to that of the rest of the world; though the latest comer, he too has a past which can not be measured by the half-dozen inches of the literary historian's rod. Archeology is repeating the lesson of geology and physical science.

I have already touched upon the discoveries in southern and eastern Africa. The consummate artists who depicted the animals of an extinct fauna, like their brethren in France and Spain, were representatives not only of *homo sapiens*, but of *homo sapiens* in a highly developed form. And think only of the conditions under which in Europe he drew his pictures on the walls and even the roofs of the caves he inhabited or carved the mammoth tusk and moulded the clay into lifelike figures! The exhibition of primitive art organized at Manchester in 1928 by the late Sir William Boyd Dawkins must have been a revelation to many of us. In the subterranean darkness of a world in which the conditions were those of Iceland or even Greenland to-day, and by such light as could be obtained from a little grease, works of art were produced worthy of being grouped with those of a fifteenth century painter. But the artistic achievement was more than matched by an achievement of an even greater nature. Man had already invented articulate language, the greatest and most outstanding invention he has ever made.

But I must leave the history of *homo sapiens* in his earlier years to the geologist and prehistoric archeologist. There is one experience of my own, however, which I will record, as it impressed me in a way that no amount of books or museum specimens could have done. Some 30 years ago I undertook to make an archeological survey of the sandstone district of Gebel es-Silsila, in Upper Egypt, for the Egyptian Department of Antiquities. A barrage was to be built across the Nile at Esna, and as the engineers wished to get their stone for it from the sandstone rocks at Silsila, it became necessary to ascertain where they could do so without destroying or injuring any remains of antiquity. In the course of my work a few miles north of the Gebel I found a wadi on the western bank of the river, which had been the bed of a torrent that had poured into the valley of the Nile from the jungle that then flourished on what is now the western desert in the Pluvial Age, when the Sahara was covered

with forest and intersected by streams. In the middle of the wadi was a huge boulder of sandstone, washed down from the plateau above and marked at about two-thirds from its base by the high-water level of the ancient torrent. Above this level the rock was covered with drawings of elephants, giraffes, and ostriches—which, it may be noted, had already ceased to exist in Egypt when the hieroglyphic script was first known in its present form. The outlines of the drawings had been chipped by flint tools, some of which I found at the foot of the boulder. Over some of the drawings had been cut a hieroglyphic inscription in the age of the Eleventh Dynasty, between 4,000 and 5,000 years ago. The inscription looked as fresh as if it had been engraved yesterday, whereas the prehistoric pictures were weathered to the color of the stone. The contrast made me realize in a startling way the enormous length of time which must have elapsed since the pictures themselves were drawn.

But historical Egypt also now has its lessons to teach us. While the literary historians have been vying with one another in the endeavor to minimize its antiquity, the spade of the excavator has made discoveries which have rightly been termed "revolutionary." At Saqqara, under the shadow of the step pyramid, generally considered the earliest of the pyramids still existing, Mr. Firth has laid bare a complex of buildings without parallel elsewhere in the country. A stately avenue of fluted columns—indicating from whence the Greeks, centuries later, derived the so-called Ionic design, a record office or library, storage magazines, tombs, and temples, have been discovered, all surrounded by a vast wall 17 meters thick and faced on both sides with the finest masonry in Egypt. It is, in fact, the masonry of modern Paris or London rather than that which we have been accustomed to associate with the Egypt of later days. And at the southwestern corner the wall is overshadowed by a circular bastion, the only circular building which ancient Egypt has bequeathed to us. Within the fortified enclosure subterranean passages cut through the solid rock lead to what may have been a memorial chapel of the king, while another passage to the north descends some 72 feet below the level of the ground to the royal tomb under the pyramid itself. The passages consist of wide and lofty corridors, the longest of which, like the tomb, has on one side a wall encrusted with small plaques covered with a blue glaze and grouped at times into the form of lotos buds or papyri bound together.[2] This wall of tiles is broken into three niches built of exquisitely white limestone, in each of which is a figure of the Pharaoh standing or in the act of running, and set in a frame on which his name and titles are engraved in hieroglyphs of extraordinary beauty.

[2] Mr. Firth points out that these bundles of papyri are the origin of the Egyptian hieroglyph dad.

Both figure and hieroglyphs are in low relief, and the figures of the king are marvels of art. Indeed, if we did not know that they represent King Zoser, described only as recently as 1895 in Bædeker's Handbook to Lower Egypt (p. 164) as "the mythical King Zoser," and that they were carved by Egyptian artists of the Third Dynasty, we should have little hesitation in ascribing them to a Greek artist of the age of Pericles. The muscles of the arms and legs, like the pose of the figures, are represented as they might have been by a Greek sculptor of the classical epoch. I know of nothing comparable with them elsewhere in Egypt, just as I know of nothing comparable with the architecture of the buildings above them; in architecture and in art alike Egypt would seem to have reached its climax in the age of Zoser, and from that period onwards, instead of progress, there was more or less decline. A still more modern touch is to be found in a side passage leading from one of the corridors of which I have spoken, which terminates in a small chamber cut in the rock and presenting a startling resemblance to a retiring chamber of to-day.

Architecture, art, and glazed tiles all testify to the long centuries of development which must have preceded the period of perfection to which they belong. And the impression made by them upon us is heightened when we come to examine the hieroglyphic script. It is already as complete and conventionalized by use as in the days of Rameses or Darius. The alphabet is there by the side of the syllabary and ideographs, and there are indications that the hieratic or cursive hand was already employed. As for the smaller objects of daily life—the furniture of the house, the jewelry and garments that were worn, or the articles of toilet—the discoveries made by Doctor Reisner in the tomb of the mother of Kheops, the builder of the Great Pyramid of Giza, prove that at the beginning of the Fourth Dynasty the culture and art of Egypt were still at their highest level. The bedstead and carrying chair of the queen, with their golden fittings, might even now adorn a royal palace. It will be remembered that Sir Flinders Petrie, when he was working at the Great Pyramid many years ago, discovered that the huge granite blocks used in its construction had been smoothed by means of tubular drills fitted with hard-stone points. The world had to wait until the era of the Mont Cénis tunnel before a similar instrument was employed again.

When we turn to Babylonia, here also the latest discoveries have pushed back the highest development of its art yet known to us to an undetermined but remote antiquity. Hitherto ancient Babylonia, whether Sumerian or Semitic, has seemed artistically deficient and inferior; its inhabitants were primarily men of business and trade, the initiators of banking and international commerce but with little artistic sense. The royal and other tombs found by Mr. Woolley

at Ur have revolutionized our judgment on this matter. The gold and silver work, the inlaid designs in shell and ivory, have revealed an art of the first order. To those of us who have been devoting a lifetime to the study of Babylonian antiquity the revelation has, indeed, been startling. Some of the inlaid designs, with their touches of modern humor, seem to belong to the European world of to-day rather than to the oriental world of the past. And yet the tombs and their contents actually belong to Babylonian prehistory rather than history. The few inscriptions found with them are not yet in the fully developed cuneiform or linear script, which already had a long history behind it when Sargon of Akkad founded the first Babylonian empire in 2750 B. C. They are, in fact, still the pictographic signs out of which first the semilinear and then the cuneiform characters slowly developed. And along with these early semi-pictographic forms goes another remarkable fact. The advanced art and culture exhibited by the objects found in the tombs is accompanied by evidence of human sacrifice on a vast scale which reminds us of Dahomey rather than of the Near East. Human sacrifice, however, was not only unknown in historical Babylonia, but its very existence at any period in the past history of the country was ignored. In the multitudinous religious texts which we now possess I can find no specific reference to it. The references which I thought I had discovered some 55 years ago have since proved to be mistaken. When Babylonian history begins the past existence of human sacrifice is even less known to its records than it is to the beginnings of Anglo-Saxon history.

And yet the royal tombs of Ur by no means belong to what, it is now clear, was the earliest period of Babylonian history. "Above the graves," Mr. Woolley tells us, "there runs, virtually unbroken, a stratum dated (by written tablets or clay jar stoppers) to the First Dynasty of Ur, about 3100 B. C., and a little below is (another) the seals from which seem to be rather earlier. Then comes (No. 3) a deep zone in which lie nearly all the graves. Below it the stratification continues, and in five further layers more tablets and seal impressions occur freely. All these are necessarily older than the "cemetery" into which the "royal tombs" were sunk. The stratification of the city itself, where house has been built over house, agrees with that of the cemetery. Here, too, there are eight successive layers, each distinguished by the remains found in it, which include inscribed objects. In one of the strata (the sixth) "which was more than 20 feet underground when the first of the royal tombs was made," four bulls' hooves of hammered copper were discovered which had belonged to a life-size statute, and in the eighth layer "the painted pottery resembling that of aeneolithic Susa and even

distant China, which hitherto (had) been reported only from Jemdet Nasr, near Kish," makes its appearance. "Below this begin to appear the black and green sherds of the El-'Ubaid type," the pottery, namely, found at El-'Ubaid near Ur. We are thus taken back to the time when the alluvial plain of Babylonia was only beginning to be formed at the head of the Persian Gulf.[3]

My own belief is that the royal tombs of Ur, modern as they are when compared with the strata below them, belong to a pre-Sumerian time and to a pre-Sumerian race, which would explain the existence of human sacrifice to which they testify. The Sumerians called themselves "the black-headed people." This implies that there was also a blond race in the country from which their black hair and eyes distinguished them, and the conclusion is confirmed by the further fact that whereas Sumerian art represents them as broad skulled, most of the early skulls discovered at Ur and examined by Sir Arthur Keith prove to be dolichocephalic. Berossus, the Babylonian historian, tells us that the plain of Babylonia was originally inhabited by peoples of various origin, and an early Sumerian poem published by Professor Langdon explicitly states that in the prehistoric days Lugal-banda, king of Dêr, on the eastern side of the Tigris, invaded the country and expelled "the wicked Murrû"—the Amorites of Semitic writers—from Erech, the future capital of a Sumerian dynasty.[4] On the Egyptian monuments, it must be remembered, the Amorites of Palestine are depicted as blonds with fair hair and blue eyes. I believe that in these blond Murrû we must see the Mesopotamian Mitannians of later history; in a letter of the Mitannian king Dusratta, Mitanni is called Murrû-khe, or "Murrû-land," and I have tried to show elsewhere that the name given to the Mitannian neighbors of the Hittites in eastern Asia Minor which has been read Kharri, or Khurri, ought to be Murri.[5] The latter have been identified with the Sanskrit-speaking tribes of whom we hear in the Hittite tablets.[6] At any rate, we may safely assume that they were of Caucasian origin. And we may, I think, further assume that the people, represented by the artistic treasures and human sacrifices in the royal tombs of Ur, were the Murrian or Amorite predecessors of the Sumerians. At Tepe Gawra, near Ninevah, Doctor Speiser has discovered two strata of cultural remains below the stratum which belongs to the Early Bronze Age and the appearance of the Sumerians. In this last, the copper objects resemble those found at Ur and

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[3] Early Art in Sumeria. Times, Feb. 11, 1930.

[4] Langdon, Weld-Blundell collection in the Ashmolean Museum, vol. 1, p. 5: Legend of Lugalbanda, ii, 12–3, "From all the land of Sumer and Akkad let the impious Amorite depart" (Kengi Uri nigin-ba Murrû galu senuzu khu-mu-zi).

[5] Ancient Egypt, pt. 3, September, 1924.

[6] Hrozný, however, would make the "Khurri" the non-Indo-European population and the Mitanni or Maiteni the Indo-Europeans (Archiv orientalni, vol. 1, No. 3, p. 296).

El-Obeid, which are dated to the period of the First Dynasty of Ur (about 3100 B. C.), whereas the earlier strata take us back to the aeneolithic epoch and the painted pottery of Jemdet Nasr.[7]

But the tombs of Ur testify to something more than an advanced art and human sacrifices. They indicate a wide international trade and the working of mines. Gold, silver, and lapis-lazuli are all found in them in profusion as well as copper. The gold probably came from the shores of the Persian Gulf, but the silver, like that of the Sixth Egyptian Dynasty, found by Sir Flinders Petrie at Abydos, was probably brought from the mines of the Taurus, while the lapis-lazuli, we are now assured by the geologists, was derived, not from northern Persia, but from northwestern India.[8] The fact is in harmony with the discoveries recently made in China and northwestern India itself. In China, Professor Anderson has found painted and polished pottery of the neolithic and chalcolithic age, which is related to the neolithic pottery discovered in Susa; similar ware has been found in Babylonia and (by Professor Garstang) at Sakche-gozü, north of the Gulf of Antioch, while the recent excavations of Professor Li at Yin in Honan—the first official excavations of a scientific character made in China—have shown not only that the Shang Dynasty (1766–1154 B. C.) was historical but that the account of its culture and script with the long preceding development and commercial intercourse implied by them was based on fact.

In India, both at Mohenjo-daro in Sind and at Harappa in the Punjab, a prehistoric civilization has been brought to light which was in close contact with that of Elam and Sumerian Babylonia. The painted pottery, the inlaid work in mother-of-pearl and ivory, even the drains in the streets, all have their connections in Babylonia, and hundreds of seals and sealings have been disinterred, which prove that there was an active trade between northwestern India and western Asia. The sealings have inscriptions in pictographic script, often accompanied by representations of an Indian buffalo or the like and of an altar of various forms. In shape and size and general character the sealings resemble those found at Susa, which also bear pictographic inscriptions as well as figures of animals. Some of the Indian sealings have actually been found in Babylonia, at Jokha, the ancient Umma, as well as in the early strata of Kish. It is evident that a large and regular trade must have existed between the two countries; a good deal of it was doubtless carried on by sea, but there must have been a land route as well. Indeed, more than 80 years ago some antiquities were discovered near Herat which included a Babylonian seal cylinder belonging to

[7] The Annual of the American Schools of Oriental Research, vol. 9, pp. 39–51.

[8] According to a Babylonian tablet (W. A. I., vol. 2, 51.1.13), the source of the lapis-lazuli was "Mount Dapara," called Tapara (Tefreret) in an Egyptian inscription of Rameses II. But this may have been the Persian depot rather than the quarry itself.

the age of the Third Dynasty of Ur about 2300 B. C., which shows that the land trade still existed at that period.[9] When this trade first began we have yet to learn, but it must go back to the time when in Elam at least the primitive pictographs had not yet been superseded by the cuneiform script. At a later date the so-called Cappadocian cuneiform tablets discovered at Kara Eyuk, 18 kilometers north of Kaisariyeh, have shown how extensive and modern in character Babylonian commerce must have been at that time. Here several thousand tablets have been brought to light, mostly consisting of trading and legal documents and including a good many private letters. At the time when they were written the copper, lead, and more especially silver mines of the Taurus Mountains were being worked by Babylonian firms whose agents had their depot and chief center at Ganis, the present Kara Eyuk. "Companies" (illâti) had been formed to exploit them and caravans traveled regularly along the roads which led from Asia Minor to Assur, the original capital of Assyria, on the one hand, and to Babylon, on the other. There was, in fact, what we should call a postal service, and one of the letters expresses the hope that the moon will shine brightly so that there might be no delay in the delivery of the mail, while another letter states that a particular route was being taken, as it was now considered safe. The tablets were enclosed in clay envelopes on which the addresses were inscribed as well as a statement of the contents.

Some of the tablets are of the nature of cheques and bills of credit. The writer states in them that they represent so many manehs or shekels of silver, gold, or copper, in return for which cloths or other goods are to be sent. Besides metals, a large trade was carried on in textiles and clothes, showing that Asia Minor at the time was not only exporting metals on a large scale, but was also the seat, like Babylonia, of an extensive textile industry. Among the articles manufactured it is interesting to note the berigani, the braccae of the Keltic languages, and our English "breeches," which can, therefore, claim a Hittite ancestry.

The principal silver mines were at the modern Bereketli, where traces of the old workings have been found extending over several miles. Gold was also mined, but in small quantities; one of the sources from which it was derived seems to have been in the northwest of the peninsula. Iron is also mentioned, but it is uncertain whether this was derived from the rock or from a meteoric source. In the later days of the Hittite Empire we are told that "black iron" as distinguished from "iron," came "from heaven," like the ba-n-pet, "metal of heaven," which denoted "iron" in the Egyptian

[9] See the Journ. Asiatic Soc. Bengal., vol. 11, pp. 316 sqq. The seal was bought by Major Pottinger, but afterwards lost—fortunately, not before a good copy of the inscription had been made by the purchaser and published in the Journal.

hieroglyphs. At any rate, iron was already worked at a considerably earlier date than the foundation of that empire; in one of the Hittite tablets a king (Anittas), who seems to have flourished about 1900 B. C., speaks of "an iron chair," and "an iron boomerang," having been brought to him from Buruskhanda, where the principal silver mines were.[10]

The date of the Kara Eyuk documents is fortunately known. The forms of the characters, as well as the Assyrian proper names occurring in them, point to the age of the Third Dynasty of Ur (2418–2300 B. C.), and this dating has been verified by the discovery of two sealings published by M. Thureau-Dangin and myself, one of which gives the name of Ibi-Sin, the fifth king of the Third Dynasty of Ur (2324–2300 B. C.) while the other has the name of Sargon I, the son of Ikunum of Assyria. We may, therefore, assign the bulk of the tablets to about 2300 B. C. They were preserved in chests of stone or terra-cotta, which took the place of our safes, and often bore the "crest" or name of the banker to whom they belonged. Thus, Professor Hrozný has disinterred one of them in the form of a terra-cotta box, on the lid of which a monkey is molded in relief.[11] They appear to have been kept in the vaults of the banks or offices of the companies established at Ganis. It is all very modern and implies a long preceding period of development and history.

We can trace it back a few centuries. In 2750 B. C., Sargon, the founder of the dynasty of Akkad and of the first Semitic Empire, carried his arms into Cappadocia, and made his way as far as a mountain called Galasu, which Doctor Weidner would identify with Ganis, and from which he brought back various plants, including the rose tree, for acclimatization in Babylonia. The chief object of the expedition seems to have been to support the Assyro-Babylonian damgari or trading agents and commercial travelers who lived there and were occupied with the trade in minerals. A sort of "commercial treaty" was made, and a century later we find Naram-Sin, the grandson of Sargon, receiving homage from Zipani, King of Ganis, and other princes in that part of the world, one of whom was Pamba, the Hittite. It is worth mention that Khati in Hittite signified "silver," so that the Khatti or Hittites would have been "the Silver men" who mined and exported that metal to the ancient world.

I need not dwell upon the length of time presupposed for the rise and development of all this trading activity with the means of traffic and use of writing which it implies. The archeological record of civilization is being steadily pushed back and the disturbing discrepancy between the facts of archeology and literary criticism is

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[10] K. B. K., vol. 3, 2, No. 22.75. The ideographs PA-GUR, which I have translated "boomerang," signify literally "a bent rod." Hrozný suggests the translation "scepter."

[11] Illustrated London News, Oct. 2, 1926.

disappearing. Civilized man is far older than the merely literary scholar has dreamed.

But the archeologist also must be careful not to exceed his evidence, and, above all, not to make assumptions which belong to a prescientific age. When I was young, the assumption that language and race were interchangeable terms was still widely prevalent, and one of my first incursions into linguistic science was an article protesting against it in the Journal of the Anthropological Institute. To-day, every scientist would acknowledge its falsity, but nevertheless the assumption sometimes appears even in quarters where it might least be expected. It can not be too often made clear that all linguistic science can do is to indicate geographical contact; where we have allied languages we have evidence of social intercourse, but nothing more.

The old fallacy, however, which confused language and race together, has been succeeded by another fallacy, which is unfortunately not infrequent in modern anthropological books. Similarities in technique are assumed without question to indicate relationship or contact in race and history. It is especially when dealing with pottery that the archeologist is tempted to assume without further evidence that such contact or relationship exists. But it is clear that mere similarity in form proves nothing of the sort when standing alone. The number of possible forms, for instance, belonging to vessels intended for use is necessarily limited; man is an inventive animal, and the same form could have been devised independently in different parts of the world. Coloration and ornament are more evidential, but even here there is plenty of room for the existence of accidental similarities. Moreover, we have to allow for primitive barter, which implies, not actual trade between two widely separated communities, but the passage of certain objects through a number of intervening hands. Thus, the painted aeneolithic pottery of China does not prove that there was intercourse between its makers and the early inhabitants of Susa and Babylonia; all that can be inferred is that at a particular period in the history of Asia there was a trade which passed slowly through a multitude of separate communities and races, generally assuming on its way peculiarities of its own.[12] Even the megalithic monuments erected to the

[12] In an article on the early pottery of Ur (Antiquaries' Journ., vol. 9, No. 4, p. 344), Mr. Frankfort justly remarks: "Generalizations are of no avail. Thinness and thickness of ware has been taken to illustrate differences in period as long as Susa only was considered; 'Musyan' has disqualified this criterion. Polychromy and monochromy of decoration no longer provide chronological indications, since Sir Aurel Stein's discoveries in Seistan and Professor Langdon's work at Jemdet Nasr suggest that certain monochrome fabrics survive and overlap the polychrome wares. Yet all these isolated qualities are still used as criteria for classification. But only if we insist on a many-sided resemblance, a resemblance affecting technique, shape, and decoration alike, before claiming the existence of relationship between wares from different sites, is there any likelihood of our not combining heterogeneous elements."

dead, of which we have heard so much of late, are in themselves of little historical value; long centuries, for example, separate those which are found in Western Europe from those which are found in Japan.

In the case of an inductive science, the false assumptions or other faults with which it starts are corrected in time. It deals with objective facts and not with the tastes and predilections of an individual scholar. And the interpretation of the facts becomes more exact and limited with the progress of the science. Archeology has outlived its years of infancy, and in its broad outlines can now take rank with geology. And like the geologist, the archeologist has had to leave catastrophic theorizing to the literary amateur. Athena did not spring full-grown from the head of Zeus. The art and culture of classical Greece, we now know, had its origin in the Greece of the Minoan and Mycenaean Age; the invasion of the barbarian north overshadowed it only for awhile, but the seed remained ready to bud and blossom again as soon as the older race had freed itself from the domination of their feudal conquerors. So, too, in Western Europe, the Dark Ages were but a break in the history of its civilization. A thousand years are but as a day in the life of civilized man, and the Renaissance meant, not that the culture of the Roman Empire was reborn, but that it had been lying like the seed in the soil, ready to spring up again and burst into leaf as soon as the conditions that environed it were favorable. In scientific archeology catastrophic theories have as little place as they have in geology or physics.

THE DISCOVERY OF PRIMITIVE MAN IN CHINA [1]

By G Elliot Smith

[With 9 plates]

At the time when Darwin published his Descent of Man comparatively little was known of the fossil remains either of men or apes, so that the discussion of the evidence of paleontology played an altogether insignificant part in his argument. Apart from the discoveries that had been made in the Neanderthal cave and at Gibraltar, nothing was known of fossil man, and what little was known was puzzling rather than helpful. Little more had then been recovered of the fossil remains of apes than a few fragments of *Pliopithecus* and *Dryopithecus.*

During the 60 years that have elapsed since those times, however, the evidence of paleontology has come to play an increasingly prominent part in the discussion of human evolution, until at the present day it is the aspect of the problem that appeals most to the man in the street when the question of man's origin comes up for consideration. It is only 40 years since any really early remains of the human family were discovered, and it is a matter of some interest to discuss the circumstances which have led to the recovery of the remains of early Pleistocene man.

Pithecanthropus was discovered 20 years after the publication of Darwin's Descent of Man. There had been much discussion, not merely on the morphological side of the question, but also on the problems of geographical distribution of apes and men that so closely affected the problem of man's evolution. The anthropoid apes ranged from Africa and Europe in the west as far as the eastern limits of the original Asiatic continent at a time when it included Borneo and Java as part of the unbroken land-mass. But whereas the chimpanzee, gorilla, and *Dryopithecus* seem to have wandered toward the west from their original home in the region of the Siwalik Hills of northern India, the orang-utans seem to have preferred the Far East, where also the gibbons, after wandering west and east, have survived. Their presence in Borneo and elsewhere

[1] Reprinted by permission, with author's revision, from Antiquity, March, 1931.

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in the Malay Archipelago suggested the possibility that man's ancestors may also have gone east.

In the year 1887 Dr. Eugène Dubois, a junior member of the staff of the anatomy department in the University of Amsterdam, was offered promotion to the position of prosector, which was the step toward the eventual attainment of the full professorship. To the surprise of his colleagues he declined this promotion, and surprise turned to amazement when he gave the reason that he was going out to the East Indies to search for fossil remains of primitive man! He was impressed by the fact that as the western area of migration of the higher Primates had failed to provide any conclusive evidence of really early man, it might be worth exploiting the possibilities of the eastern route and determining whether the archaic members of the human family may not have followed the footsteps of the ancestors of the orang-utan. He resigned his position in Amsterdam and went out to the Indies as an army doctor, and began to search in the caves of Sumatra and the fossiliferous deposits in Java for the object of his quest. The most amazing aspect of this adventure was Doctor Dubois's discovery of the sort of thing that had inspired his mission. In 1891 he found in the gravels on the banks of the Solo River, which natives of central Java refer to as Bengawan or "Great River," the fossilized remains of a braincase, a couple of teeth, and a femur. When these fossils were shown at the International Congress of Zoologists in Leyden in 1894 they provoked a controversy which has continued ever since then.

In the first place the nature of the braincase was a matter of dispute—whether it was part of a hitherto unknown gigantic ape or of an equally unknown primitive type of human being, or, as Doctor Dubois himself maintained, a creature that was not strictly either simian or human, but a link between the two, the position of which was so enigmatic that it would be misleading to call it either an ape or a man. This problem, in spite of nearly 40 years of discussion, is still in dispute. Although the majority of anthropologists admit *Pithecanthropus* to membership of the human family, there is still wide divergence of opinion as to what his position in the family is, whether he is in the direct line of descent of later men, or whether he represents a specialized and divergent member of the family. Then again there is the question as to whether or not the teeth and the thigh bone which were found in the same gravels, and in a similar state of fossilization, are parts of the same or similar individuals, or whether the femur of a more definitely human type of being happened to be deposited in the same bed of gravel with the remains of the Ape Man, who was a fantastic caricature of a human being. There are the widest divergences of opinion even at the present time on this issue.

Then again the question of the geological age of the fossils has been a subject of controversy. When Doctor Dubois first discovered the fossils he was impressed by the fact that the associated mammalian remains seemed to be identical with types which occur in the Pliocene beds in the Indian Siwaliks. Hence he regarded the fossils as evidence of the former existence in Java of Tertiary man. The further study of these remains, and in particular the gradual accumulation of knowledge regarding the fossil mammalia of Asia, have since convinced most paleontologists that the age of the Java fossils is Pleistocene and not Pliocene. Two years ago (February 22, 1929) Prof. Henry Fairfield Osborn, the president of the American Museum in New York, called attention (Science, vol. 69, p. 216) to certain facts, which had impressed Professor Dietrich of Berlin and himself, that the proboscidean and other mammalian remains associated with the human fossils belong not to the Early Pleistocene but to the Middle Pleistocene Age, suggesting that the Ape man of Java was relatively much more recent than had hitherto been supposed.

The total result of these discussions is that the precise age and the significance of the fossils found by Doctor Dubois 40 years ago are still matters of lively controversy and considerable doubt.

Nearly 30 years ago the late Mr. Charles Dawson, a lawyer practising at Lewes in Sussex, who had then devoted more than 30 years of his life to the hobby of hunting for fossil remains of extinct animals in the Weald of Sussex, was attending a land court at the Manor of Barkham near Piltdown, when he noticed the road leading up to the manor house being repaired with flint. During the sitting of the manorial court over which he was presiding, instead of giving the whole of his attention to the legal business in hand, he was unable to restrain his roving fancies from wondering why people should be using such poor material as flint to repair a road when, as he thought, the cost of bringing it from the nearest source known to him, which was more than 5 miles away, would have been almost sufficient to have paid for proper road metal. Hence, as soon as the court rose for lunch he went out to make further enquiries, and discovered from the workmen that the reason why flint was being used was that it was present on the spot. The road itself crossed the small patch of gravel which the men were digging up to mend it. Mr. Dawson instructed the workmen to keep a lookout for any fossil remains which they might find in this bed of gravel, and from time to time, whenever any excavation was going on, he visited Barkham Manor to keep a watch on the excavation.

Years afterwards he visited the spot to find the workmen, in defiance of the instructions he had given them, throwing stones at what

they thought was an old coconut obtained from the gravels. He at once rescued the fossilized remains of a piece of a phenomenally thick human braincase, and began excavating there and recovering other pieces. The massiveness of the skull and the Pleistocene age of the deposits suggested to Mr. Dawson's mind that he had found part of the braincase of the only Pleistocene man at that time known in Europe. The Heidelberg jaw had been found in 1907 and is all that we know of this peculiar type of the human family which probably represents the distinct genus of *Palaeanthropus*. In 1912 he took the fragments to Dr. (now Sir Arthur) Smith Woodward, at that time Keeper of Geology at the British Museum (Natural History), and they set to work to dig the gravels at Piltdown.

In the summer of 1912 they found a fossilized jaw, which at once convinced them that they were dealing with a creature totally distinct from the Heidelberg man, one who was very much more primitive and apelike and also much older even than that Pleistocene man of Germany. The announcement of these discoveries, at a meeting of the Geological Society in London in December, 1912, started a series of controversies which were even livelier and more confusing than those which had raged since 1894 around *Pithecanthropus*. For there was not only the same element of doubt as to the significance and age of the Piltdown fragments, but there were several new elements of controversy in the Sussex discoveries. The question of age was subject to the same uncertainty as I have mentioned in the case of *Pithecanthropus;* the fragments of bone had been deposited by running water in gravels; and in these gravels there were the remains of Pliocene as well as Pleistocene mammals. As the skull itself showed no signs of rolling, such as many of the Pliocene fossils displayed, it was assumed that it was contemporaneous with the undamaged Pleistocene fossils. But there were many elements of uncertainty in the determination of the geological age of the specimens, and recently Professor Osborn has been putting forward a view in opposition to the one which is now commonly accepted, that the Piltdown skull may possibly be Tertiary in age and not Quaternary as was supposed. "The problem is whether it came from a Pliocene gravel bank with a primitive elephant and mastodon, or from a Pleistocene gravel bank with a primitive hippopotamus." (Science, 1929, p. 217.) There has, moreover, been the liveliest discussion as to whether or not the jaw which was found at Piltdown was not that of a chimpanzee rather than of a human being. Even after 20 years of discussion there is no complete consensus of opinion upon this issue.

The problem of the precise mode of reconstruction of the skull gave rise to unseemly and wholly unnecessary discussions which

served to create a widespread confusion in the minds, not merely of the general public, but even of anatomists and paleontologists, and profound doubt as to the importance and precise significance of this great discovery in Sussex. This lack of confidence in the validity of the remains of *Pithecanthropus* and *Eoanthropus* was intensified by the fact that these two doubtful members of the human family were so dissimilar that they seemed to be hardly compatible with one another. This increased the doubt as to whether two primitive members of the human family who were supposed to be roughly contemporaneous one with the other—that is, Early Pleistocene in age—could differ so profoundly as these two skulls did, although the whole breadth of the great continent of Europe and Asia separated them from one another. So profound is the scepticism concerning Piltdown Man that important treatises on the fossil remains of man published in Germany during the last few years have either refrained altogether from referring to the Piltdown discovery (which obviously is of crucial importance) or have stated that the issue is so doubtful as to be excluded from the argument.

Even those of us who have always been convinced that both *Pithecanthropus* and *Eoanthropus* were genuine members of the human family, were somewhat puzzled to know how to define their relations to one another, and precisely what light they shed upon the process of the evolution of later types of human beings.

The discovery of *Sinanthropus* in China has put an end to this uncertainty and marks a new epoch in human paleontology. The skull found at Chou Kou Tien on December 2, 1929, has dissipated the chief elements of doubt and uncertainty in regard to the other two genera of the human family, for it not only provides us with much fuller and unequivocal information concerning a third and hitherto unknown genus of early Pleistocene man, but in addition it establishes a bond of union between the other two types, and shows that the Ape Man of Java and the Dawn Man of Piltdown are not really incompatible with one another. Many of the most characteristic features of these two divergent types are combined in the same individual of the genus *Sinanthropus*. Hence it clears away the mists of doubt and suspicion. Thus the discovery in China is not only a tremendous contribution to the exact knowledge of early Pleistocene man, but in addition it gives a respectability to these other early men, whose remains were being discredited, and a coherence to our knowledge of all three types which thus establishes upon a sure foundation our knowledge of the most primitive men so far recovered.

The discovery of the Peking remains is a romantic story, differing from the finding of the other two genera, just as the nature of the

circumstances under which the fossils were deposited differs from those revealed in Java and in Sussex respectively. The remains of the Peking man were not deposited by running water in river gravels, but left by their original owners on the floor of a cave of Ordovician limestone where they and a large series of mammals dwelt in Early Pleistocene times. Hence the geological age is certain. The elements of doubt which arise in the case of *Pithecanthropus* and *Eoanthropus* do not arise in the case of *Sinanthropus*.

Nearly 30 years ago Doctor Haberer purchased in a druggist's shop in Peking a collection of " dragon's bones " which he sent to Prof. Max Schlosser in the University of Munich. Shortly afterwards, in 1903, Professor Schlosser published (in Abh. königl. Bayerisch-Akad., Wiss. Math. Phys. Kl., vol. 22, pp. 20–21, 1903) a memoir under the title " Die fossilen Säugethiere Chinas nebst einer Odontographie der recenten Antilopen," giving his identifications of the series of fossil remains he was able to recognize among this collection of Chinese drugs. On pages 20 and 21 of this memoir there is a section called " The Description of the Primate Types," which is of such exceptional interest and importance that I shall translate that portion of the description which is defined as " ? Anthropoide g. n. et sp. ind." ? In his account Professor Schlosser says, " In the collection recently sent by Doctor Haberer from Peking there was a left upper third molar, either of a man or a hitherto unknown anthropoid ape. This tooth is completely fossilized and is quite opaque. Moreover it exhibits between its roots a reddish clay such as is found only in teeth which belong to the Tertiary period and are earlier than the loess. Hence it is probable that a Tertiary age should be ascribed to the specimen. Unfortunately the tooth is already much damaged and its surface corroded by the roots of plants, so that the original appearance of its surface can not be accurately determined." After giving an account of the position of the various projections on the surface of the crown in comparison with other teeth, and describing the form of the body of the tooth and its roots with their respective measurements, Professor Schlosser proceeds to consider how to determine the zoological status of the original possessor of the tooth. The form of the tooth and morphology of the roots are distinctly manlike. On the other hand the state of preservation of the tooth makes it clear that it is of remote antiquity, possibly as old as the Tertiary period, which suggests the improbability of it belonging to the genus *Homo*.

In fact the Tertiary existence of any type of man is not yet established. Hence the possibility has to be considered whether this tooth may belong to a hitherto unknown genus of anthropoid ape, which in the structure of its teeth approached more

nearly to man than any other known anthropoid ape. Another possibility, he says, is that the tooth may be that of a human being which in some way became displaced and got into the Tertiary beds although belonging to a more recent period. He suggests, for instance, that possibly the tooth was only of Pleistocene age, which raises the difficulty that the state of fossilization is such as he has found only in teeth which are either Tertiary in age or are referable to the very beginning of the Pleistocene. He admits that he can not pretend to distinguish between the state of fossilization between the earliest Pleistocene and the Tertiary. He admits that a definite answer to this riddle must necessarily be only tentative—for no other early human remains except *Pithecanthropus* were then available for comparison. No useful purpose would be served by comparing this third molar tooth (with its marked difference in size and much more strongly reduced roots) with the tooth of *Pithecanthropus*, the roots of which were much more exceptionally divergent. He calls particular attention to the fact that the fossil found in China presents a much nearer likeness to the tooth from the Indian Siwaliks which Lydekker has described as *Troglodytes sivalensis*, to which Dubois refers as *Palæopithecus sivalensis*. The third molar tooth in this Indian anthropoid presents a close resemblance to the Chinese tooth. It is distinguished, however, only by relatively slight differences in size and the position of the roots. After detailed comparisons between these teeth of fossil anthropoids and primitive men (including *Pithecanthropus* and the Neanderthal remains from Krapina) Schlosser refers to the possibility that the tooth from Peking may be the remains of the oldest human being known at that time and one that displayed a closer likeness to the apes than any other known fossil. While admitting that, however unpardonable it might be tacitly to evade the issue, it is important to try to define a systematic position which obviously could not be finally determined by the scanty evidence at that time available.

Hence he defines the aim of his communication to suggest to later investigators who may enjoy the privilege of carrying out excavations in China the desirability of searching for the remains either of a new fossil anthropoid, a Tertiary man, or an Early Pleistocene human being. In recording the complete realization of the third possibility adumbrated by the veteran German paleontologist, it would be unpardonable not to refer to Professor Schlosser's insight and courage. He correctly predicted the age and the nature of the type of being whose damaged tooth came into his possession without any indication either of its provenance or of the geological circumstances under which it had been recovered. One can not withhold

admiration for his wonderful imagination which enabled him to make this amazingly accurate prediction, which the discoveries of the last five years in China have so amply corroborated.

This brilliant forecast was made in 1903, but nothing further was done towards the realization of it until the year 1921, when Prof. J. Gunnar Andersson, the Swedish geologist who was acting as the Adviser to the Geological Survey of China, was directed to a deposit of fossil bones at Chou Kou Tien through overhearing the chatter of his native workmen. When he started to examine the rich deposit of fossil bones in the cave at Chou Kou Tien he found amongst these remains a piece of quartz, and at once remarked to his assistants, "This is primitive man," implying by that statement that as quartz did not naturally occur in this spot, some early Pleistocene human agency must have been responsible for its presence among the bones which he was examining. In a way this inference is almost as remarkable as that which Professor Schlosser had made over 20 years previously.

The funds available for the Chinese Geological Service were inadequate to carry out the examination of these fossils with the thoroughness which their importance merited, but Doctor Andersson obtained from Mr. Ivar Kreuger, of Stockholm, financial aid which enabled the investigations to be continued and extended.

The material obtained from Doctor Zdansky's excavations at Chou Kou Tien in 1922 was taken to Professor Wiman's laboratory in Upsala for examination; and in 1926, on the occasion of the visit of the Crown Prince of Sweden to Peking it was announced that two human teeth had been found, an immature left lower molar, and a somewhat worn adult right upper premolar.

In the Bulletin of the Geological Society of China, volume 5, Nos. 3–4, page 284, 1927, Doctor Zdansky gave an account of these teeth, the concluding two paragraphs of which I quote in his own words:

> Granted the human origin of the teeth, there arises the question of their relation to the living and prehistoric races of man. . . . I am indeed convinced that the existing material provides a wholly inadequate foundation for many of the various theories based upon it. As every fresh discovery of what may be human remains is of such great interest not only to the scientist but also to the layman, it follows only too naturally that it becomes at once the object of the most detailed—and, in my opinion, too detailed—investigation. I decline absolutely to venture any far-reaching conclusions regarding the extremely meagre material described here, and which, I think, can not be more closely identified than as Homo sp.
>
> The above has been written largely because I find I am credited, in certain quarters, with the discovery of the "Peking man" (vide daily newspapers), which is supposed to be of Tertiary age. Leaving until a future date the publication of a detailed description of the fossil fauna from Chou Kou Tien,

my purpose here is only to make it clear that my discovery of these teeth (which are of Quaternary age) should be regarded as decidedly interesting but not of epoch-making importance.

Dr. Davidson Black, however, took a different view of the significance of the teeth. To him they were definitely of epoch-making importance. Moreover, he had the courage to act upon his conviction. He had been profoundly influenced by the memoir published in 1915 by the late Prof. W. D. Matthew, F. R. S., "Climate and Evolution." (Ann. New York Acad. Sc., vol. 24, 171.) In fact, the possibility (suggested by Doctor Matthew's argument) of the discovery of primitive man in China decided Dr. Davidson Black to accept the invitation, which he received after the war, to join the staff of the Anatomy Department in the Peking Union Medical College. The reality of Doctor Black's conviction was known to me, not only by statements in his private letters, but also in the memoir which he published in 1925 entitled "Asia and the Dispersal of Primates." (Bull. Geol. Soc. China, vol. 4, no. 2, p. 133.) Hence when, a year later, Doctor Zdansky found human teeth in the early Pleistocene or, as was then thought, late Pliocene, beds, Dr. Davidson Black regarded this as a definite realization of the aim which he had set before him several years before, and naturally regarded the discovery as truly epoch-making.

In a communication which, at the request of Doctor Andersson, he made at the scientific meeting held in Peking on October 22, 1926, he emphasized these considerations, and was able to interest Dr. Henry Houghton, then director of the Peking Union Medical College, and Edwin Embree, then secretary of the Rockefeller foundation, to support an appeal for financial help to carry on the search at Chou Kou Tien. The late Dr. Richard Pearce, at that time director of the medical division of the Rockefeller Foundation, so far appreciated the significance of the possibilities that he induced the Foundation to make an appropriation for two years' work on the site.

This project met with immediate success, for on October 16, 1927, Dr. Birger Bohlin found a human lower molar tooth in the deposit at Chou Kou Tien, where Doctor Zdansky found the teeth reported on October 22, 1926. On December 2, 1927, Dr. Davidson Black announced to the Geological Society of China this important discovery and his courageous decision to use it as evidence for the creation of a new genus and species of the human family.

On the suggestion of Dr. A. W. Grabau, professor of paleontology in the National University of Peking, he called it *Sinanthropus pekinensis.* The age of the deposits in which the fossils were found was thought at this time to be Upper Pliocene; but a more careful

sifting of the evidence provided by the associated mammals subsequently led the geologists to decide that the real age was Lower Quaternary (very early Pleistocene). Professor Schlosser in 1903 and all subsequent writers for the next quarter of a century believed that fossils found in deposits earlier than the loess of the Chili plain were Pliocene. But investigations during the season 1927–28, fully recorded in the exhaustive report published by Père Teilhard de Chardin and Dr. C. C. Young (Bull. Geol. Soc. China, 1929, p. 173), established the age of the fossils as Early Pleistocene.

Dr. Davidson Black claimed that the morphology and the proportions of the tooth left no doubt either of its human origin or of the fact that it is generically distinct from all other known human types. He came to the conclusion that its original possessor was a child corresponding in age to that attained by modern children at 8 years, and presumed that it was derived from the same jaw as the lower premolar tooth whose discovery was reported in 1926 by Doctor Zdansky.

In 1903 Professor Schlosser had emphasized the fact that while the tooth he was describing on that occasion differed from those of other known human and simian remains, morphologically it was essentially human in type, but revealed certain remarkable points of similarity to one of the fossil apes from the Siwalik Hills. The tooth found in 1927, like that of 1903, was partly embedded in a stony matrix which, in addition to the condition of mineralization of the tooth itself, corroborated the extreme age of the specimen.

In a monograph published in 1927 (Palaeontologia Sinica, ser. D, vol. 7) Dr. Davidson Black gave a detailed description of the tooth found by Doctor Bohlin in that year. He called attention to its distinctive characters, and contrasted it with a series of primitive human and simian teeth. He provides ample justification for his action in creating a new genus and species of the human family. He shows how every character of the tooth, the form and proportions of the crown, the peculiarities of the roots and the size and form of the pulp cavity all agree in conferring upon *Sinanthropus* a distinctive position intermediate between man and ape. Moreover, he shows how generalized are the characters of the tooth, so that it enables us to understand how the peculiarities revealed in the later types of the human family have been derived from this extremely primitive type by differentiation of some of the potentialities so clearly manifest in this interesting tooth. He showed also with great clearness how the pattern of the crown showed a distinct likeness to that revealed in the fossil ape *Dryopithecus*.

In spite of the very thorough and complete demonstration of the fact that the tooth of *Sinanthropus* was of early Pleistocene age and

so definitely different from that of all other known human teeth (an extremely generalized human type presenting obvious analogies to the conditions found in the fossil apes which most nearly conform to the human type) Doctor Black's action in creating a new genus did not meet with any widespread support. A year later, however. the discovery made by Dr. Birger Bohlin, working in conjunction with Dr. C. C. Young and Mr. W. C. Pei, of fragments of two jaws and braincases, provided evidence which confirmed the validity of the genus founded in 1927. The tooth upon which Doctor Black based his definition of the new genus conformed in character to the two teeth whose discovery was announced in 1926, as well as to the tooth described by Schlosser in 1903, and there can be no doubt that these four teeth all belong to *Sinanthropus.* One of the teeth found by Doctor Zdansky in 1926 probably came from the same jaw as the type specimen found in 1927. The two jaws found in 1928 contained a number of teeth conforming to the same characteristic morphological types as that found in 1927. Both jaw fragments, one of a child and the other of an adult, display very significant peculiarities in the chin region. The oblique slope of the anterior surface is comparable only to that of anthropoid apes and the Piltdown jaw; and a peculiar conformation of the lingual aspect of the jaw is analogous to, though not exactly identical with, the peculiarities of the jaw found at Piltdown in 1912, which has been a subject of the liveliest controversy ever since.

While the finding of this peculiar apelike type of jaw in association with fragments of braincases, which are unquestionably human, provides corroboration of the justice of regarding the tooth of 1927 as a new genus, it also affords evidence which can not be ignored in support of the validity of regarding the jaw found at Piltdown as part of the same human individual whose broken skull was also found alongside it. The features of the jaws of *Sinanthropus* at first raised the possibility that the fossil man of China might be more nearly akin to the early Pleistocene man of Piltdown than to the Ape Man of Java. It would, however, be more accurate to say that, as nothing whatever is known of the type of jaw of *Pithecanthropus*, the only human jaw susceptible of comparison with the Peking jaws was that found at Piltdown. The contrast between the teeth of *Pithecanthropus* and those of *Sinanthropus* suggest that there must have been a considerable difference between the jaws of those two primitive genera. In 1929, however, the finding of an almost complete braincase of *Sinanthropus* by Mr. W. C. Pei revealed a type of skull which, while it was still embedded in the hard matrix of travertine (involving the base and a greater part of the sides of the skull) seemed to be much more nearly akin to the skull of *Pithecanthropus*

than to that of *Eoanthropus.* While there is this obtrusive general resemblance to *Pithecanthropus*, however, it is important not to minimize the peculiarly significant expansion of the frontal and parietal parts of the braincase which so definitely distinguishes it

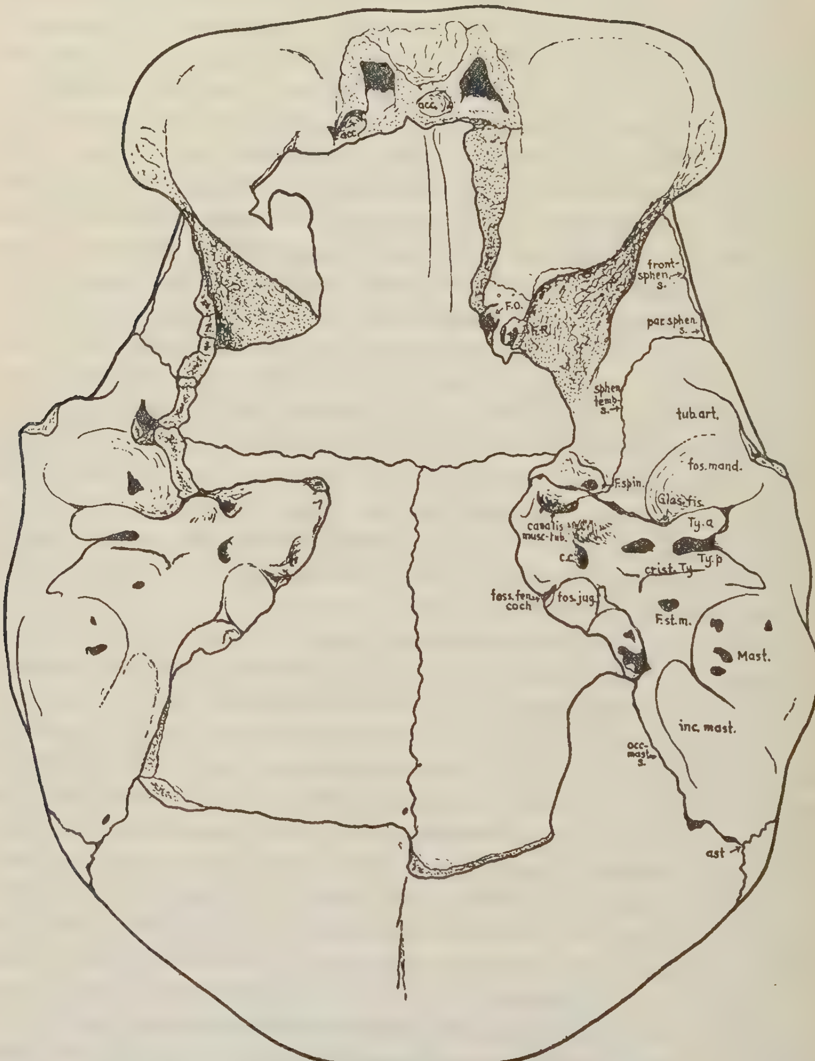

FIGURE 1.—Base of the Peking skull after removing the travertine from its interior

from the skull of *Pithecanthropus.* There can be no doubt, however, that just as the finding of the jaws in 1928 suggested the possibility of some kinship with the Piltdown man, the skull found in 1929 caused opinion to swing in the other direction and suggested a nearer kinship with *Pithecanthropus.* In 1930, however, when after four

months of intensive work, Dr. Davidson Black completely liberated the skull from the matrix of travertine, the braincase was revealed with a curious blend of characters hitherto regarded as distinctive, some of them of *Pithecanthropus* and others of *Eoanthropus*. The combination in the same specimen of peculiar characters hitherto regarded as incompatible one with the other was not only important as a revelation of the extremely primitive and generalized qualities of *Sinanthropus*, but, what was even more important, it formed a link between the other two genera of early Pleistocene men, concerning the validity and significance of which there had been so much doubt and suspicion. Hence the skull found in 1929 not only established on a firm foundation our knowledge of primitive man to which it gave coherence and in which it inspired confidence, but in addition it revealed a type which was so primitive as to enable us to visualize the characters of the common ancestor of all three genera.

If the size and form of the eyebrow-ridges (pl. 4) and the median frontal crest (pl. 2) suggest a kinship with *Pithecanthropus*, the form of the posterior aspect of the skull (pl. 1, fig. 2) presents a marked contrast to the Java fossil and a definite likeness to *Eoanthropus*.

As long ago as 1903, Professor Schlosser defined the contrast between the tooth he was discussing and those of *Pithecanthropus*, differences which have been still further emphasized by Dr. Davidson Black with the fuller material at his disposal.

The braincase of *Sinanthropus* differs from that of *Pithecanthropus* not only in the matter of the local expansions of the frontal and parietal areas, but also in its general form and the characters of its cranial bones, for the exceptional thickness of the cranium (pls. 5 and 6), and the peculiar architecture of the bones reproduce conditions which hitherto have been regarded as distinctive of *Eoanthropus*. The form of the surprisingly small cranial cavity presents a significant contrast to that of *Pithecanthropus*, being narrower and loftier, and free from the grosser type of distortion revealed in the broad flat endocranial cast of *Pithecanthropus*. The braincase of *Sinanthropus* reveals many features which are unknown either in the Ape Man of Java or in the Piltdown skull, and throws a great deal of light upon the characters of the common ancestor of the human family, from which all these genera had been derived. One of the most striking illustrations of this fact is the peculiar form of the mastoid region of the temporal bone, recalling as it does the condition found in the new-born child and in the adult anthropoid apes, for it lacks that salient character which is so distinctive of the adult human of other genera (pls. 3 and 4, fig. 1).

The skull found in 1929 is that of a young adult corresponding in the state of its development with the condition found in modern human skulls at about 16 years of age. When the skull was first examined Dr. Davidson Black was impressed by the grace of its contours in comparison with the uncouth outlines of *Pithecanthropus*, and suggested the possibility that it might be female, with the reservation, of course, that the evidence at our disposal regarding this hitherto unknown type of being was altogether inadequate for any definite decision upon this matter. Its grace, however, may be due to its primitiveness and the fact that it is free from those secondary distortions which give the degenerate *Pithecanthropus* its bizarre character. The discovery of another braincase (pl. 9) was made in July, 1930, by recovering from material brought in from the Chou Kou Tien cave (in October, 1929) a series of fragments which naturally articulated one with the other to form the greater part of the calvaria. This discovery of a skull of another individual probably more than 10 years older than the one found in December, 1929, revealed a more lightly built skull with small eyebrow ridges, a less prominent forehead and less obtrusive parietal eminences, which both Dr. Davidson Black and I consider to be probably of different sex from the other skull. It seems probable, however, that the skull reported in July, 1930, may prove to be female and the other skull (found on December 2, 1929) male; but at present neither opinion can be said to be based upon any really decisive evidence. The discovery of a second skull enormously enhances the value of the information we have because it permits comparisons to be made. In Figure 2, SD indicates the place where this skull was found, a few feet above the spot (SE) where the skull was found in December, 1929.

In the material found in 1928 there are remains of two other broken skulls (still embedded in travertine), which provide other important comparative material for studying the range of variation of the skulls.

Whether or not the Peking man was older than the fossils found in Java and Sussex, there is no doubt that he represents a more primitive type. His characters are more generalized, some of them distinctly reminiscent of man's simian ancestry and others strangely foreshadowing the qualities hitherto regarded as distinctive of *Homo sapiens*. In other words, *Sinanthropus* enables us to picture the qualities of the original members of the human family by revealing a type which, though human, was curiously ape-like, and obviously close to the main line of descent of modern man.

The work of investigation and of recording the results has been carried on with exceptional thoroughness and imaginative insight.

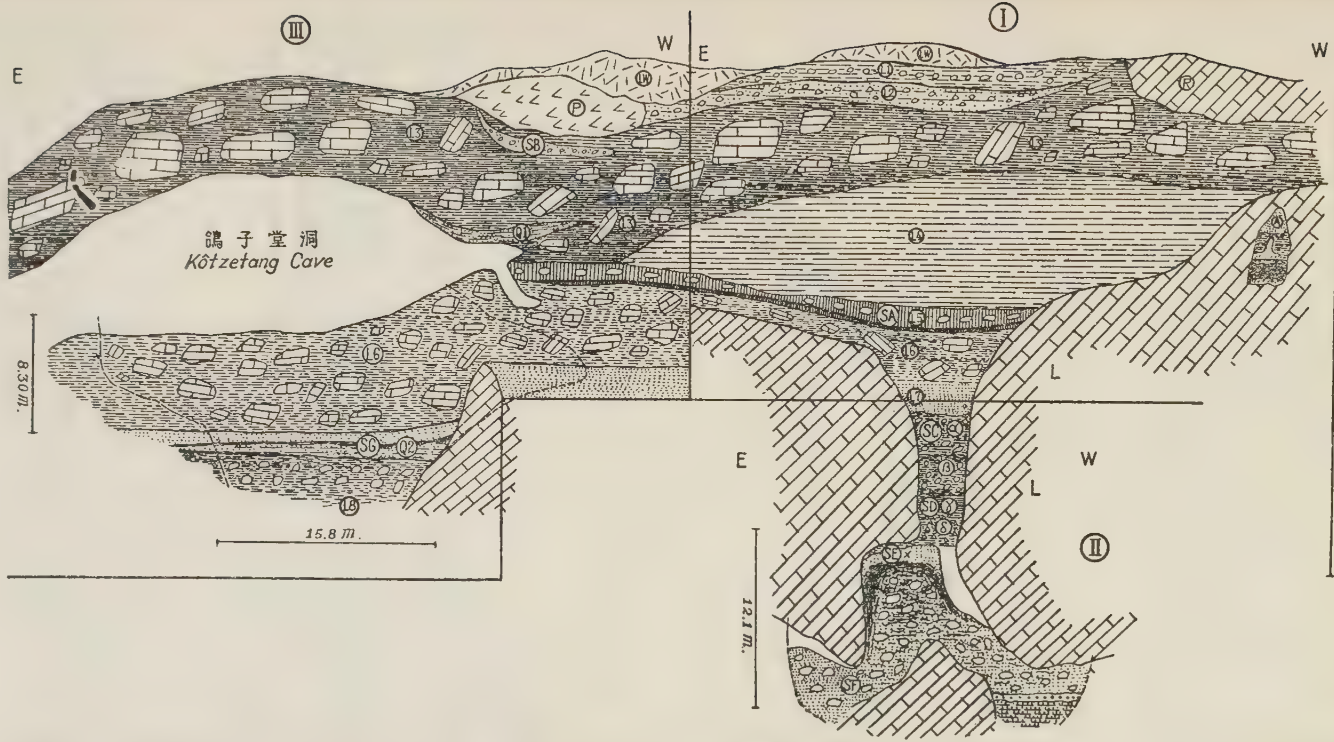

FIGURE 2.—Drawing from W. C. Pei's memoir in which the diagram of a section made by Teilhard and Young of the main deposit at Chou Kou Tien (I) has been combined with a further section of the lower cave (II) excavated in 1929 and 1930, and the Kôtzetang Cave (III) excavated in 1931

The line of the section passes from east (E) to west (W). The various places marked with the letter "S" (SA to SG) indicate where fragments of *Sinanthropus* have been recovered. SE is the spot where the skull was found on December 2, 1929, and SD, higher up, is where the blocks of limestone were obtained in October, 1929, from which, in July, 1930, the second skull was recovered. SA and SB are the places where the original fragments of *Sinanthropus* were found. QI and QII, in the Kôtzetang Cave, represent the places where deposits of quartz have been found; LW, lime waste; P, rubbish; R, limestone blocks presumed to be the residual part of the roof; LI to LVIII, various layers of deposits.

It was hoped by Dr. Davidson Black that the prompt publication of bulletins and the wide circulation of manuscript reports even before they were published, would have prevented the development of such misunderstandings as had marred the discussions of the fossil remains of man in the past. In spite of these precautions, eminent paleontologists in Germany and France are already claiming that the Peking man belongs to the genus *Pithecanthropus;* others in America have suggested that he is merely a Far Eastern example of Neanderthal Man; and others again that the Chinese fossils were not human.

Having made a careful examination of the actual fossils in Peking and compared them with human and simian skulls, and the casts of the other kinds of extinct members of the human family, I can

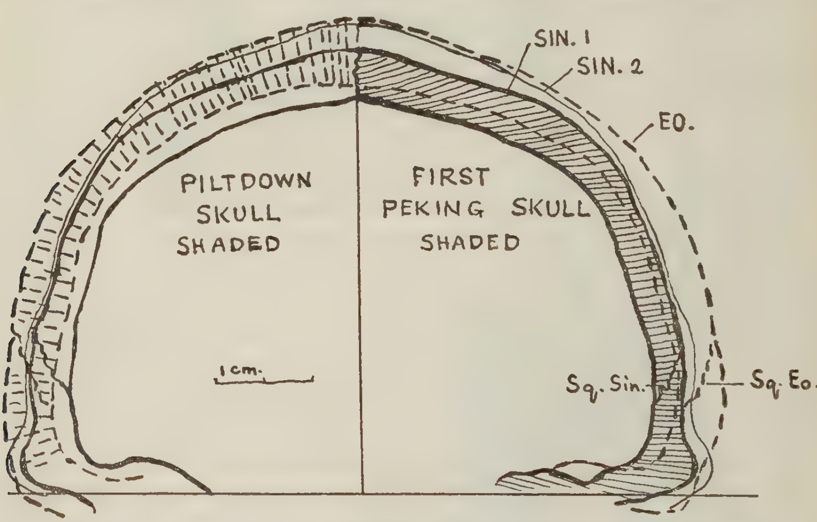

FIGURE 3.—Transverse sections in the plane of the acoustic meatus of the Peking skull (SIN. 1), of the second Peking skull (SIN. 2), and of the Piltdown skull (EO.)

confidently support the opinion of Dr. Davidson Black that *Sinanthropus* is an undoubted member of the human family, who reveals in every part of his skull and teeth evidence to distinguish him from all other known human types, and to justify the separate generic rank suggested to define his status.

THE INDUSTRIES

In studying the remains of early man it is always a matter of particular importance to search for the tools and implements which might bring the human beings into association with some definite phase of industry. At Chou Kou Tien, in spite of the most careful search in the caves during four years, no trace whatever of im-

plements had been found. When it is considered how vast a quantity of fossils were recovered and the scrupulous care which has been exercised in the search, it seems something more than a mere coincidence that no trace of any stone implements were found. Not only were the various excavators on the constant lookout for such artifacts (in particular Father Teilhard has been looking for archeological evidence), but after the material was removed from the caves, a group of boys was put on to sift the material once more to make quite certain that no such evidence had been overlooked by the geological explorers. It must not be forgotten, however, that Doctor Andersson in 1921 found pieces of quartz in association with the fossil bones, and that in the later stages of the excavation Mr. Pei found further examples of this alien material. Those who have been searching in vain for evidence of human craftsmanship on this site were being forced to the conclusion that the Peking man was in such an early phase of development as not yet to have begun to shape implements of stone for the ordinary needs of his daily life.

In the spring of 1931, however, Mr. Pei began to examine the adjoining cave of Kôtzetang (fig. 2) and was at once rewarded by discoveries of exceptional interest and significance. In association with two large fragments of a human jaw and three pieces of a brain case (found at SG, fig. 2) thousands of pieces of quartz, quartzite, and other alien stones were found. Some of these had been fashioned into implements which the discoverers regard as the crudest possible type of flaking, but the Abbé Breuil claims to be surprisingly advanced. (Bull. Geol. Soc. China, 1931; also Man, Jan. and April, 1932.) Not only so but Mr. Pei and Dr. Davidson Black found conclusive evidence of the use of fire and, according to the Abbé Breuil, of the splitting of the bones of large mammals to obtain marrow, the making of implements of bone and deer-horn, and the working of the brain-cases of deer to make drinking cups. No longer then is there any room for doubt that the most generalized member of the human family had already acquired the skill and the intelligence which are the hall-marks of his humanity.

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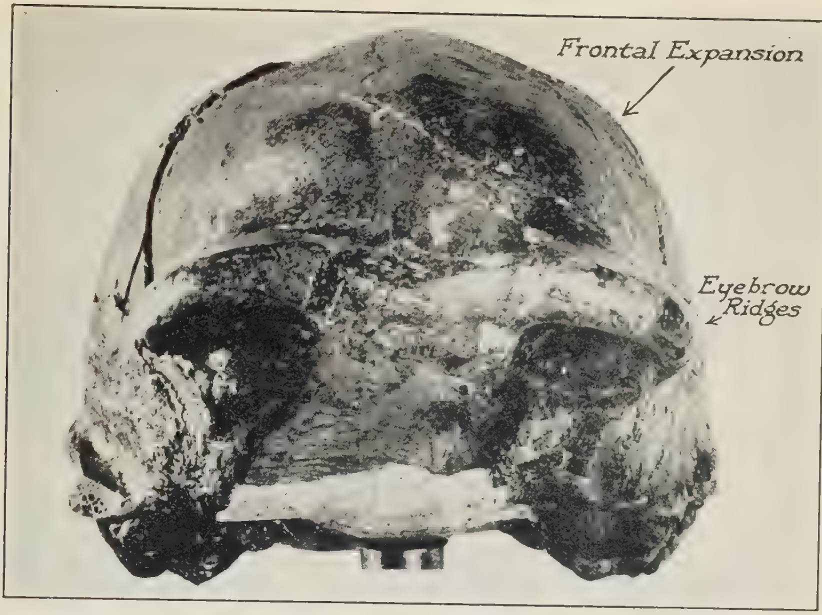
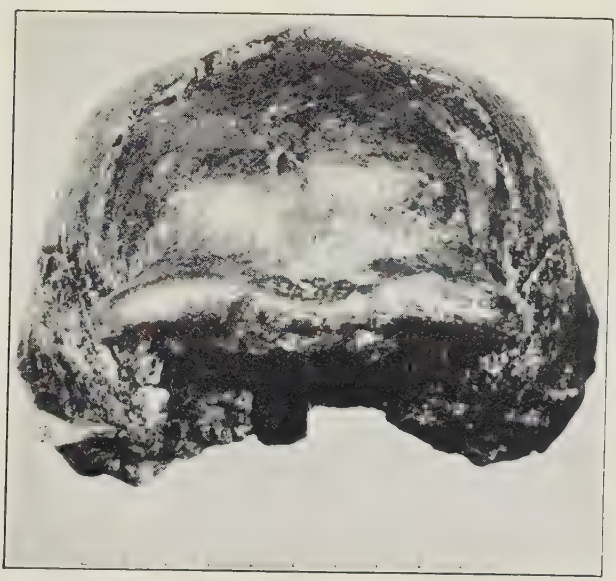


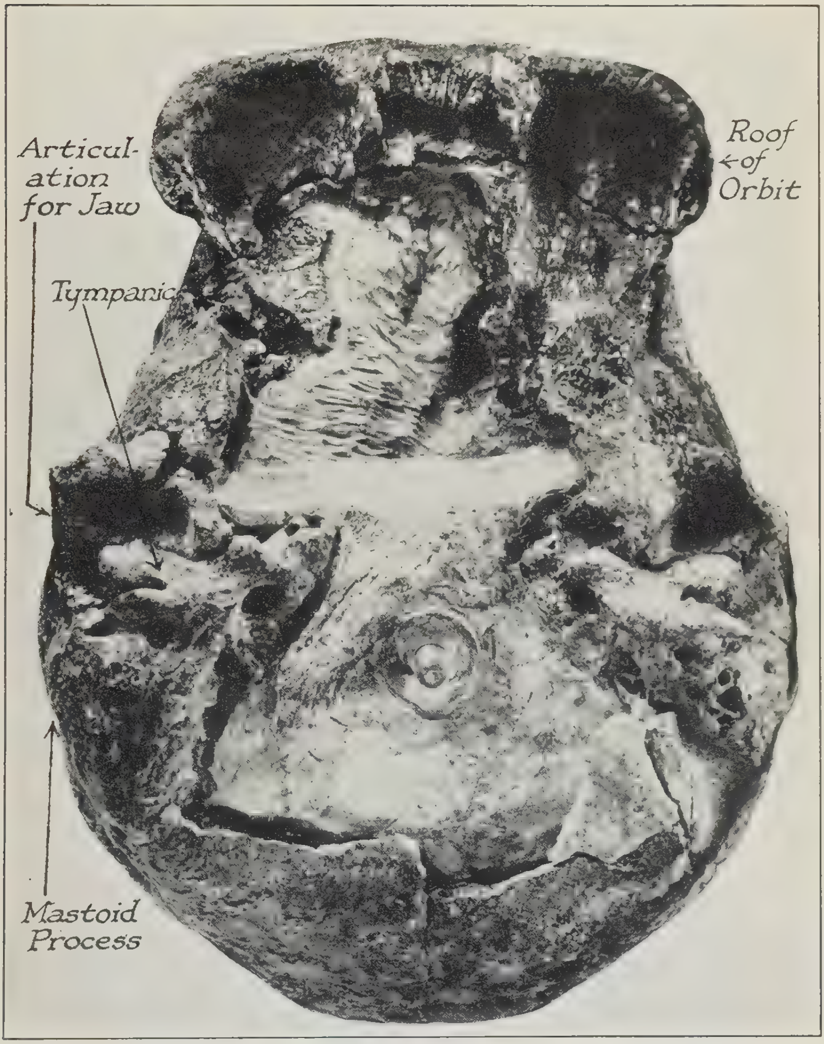
1. FRONT VIEW OF THE PEKING SKULL



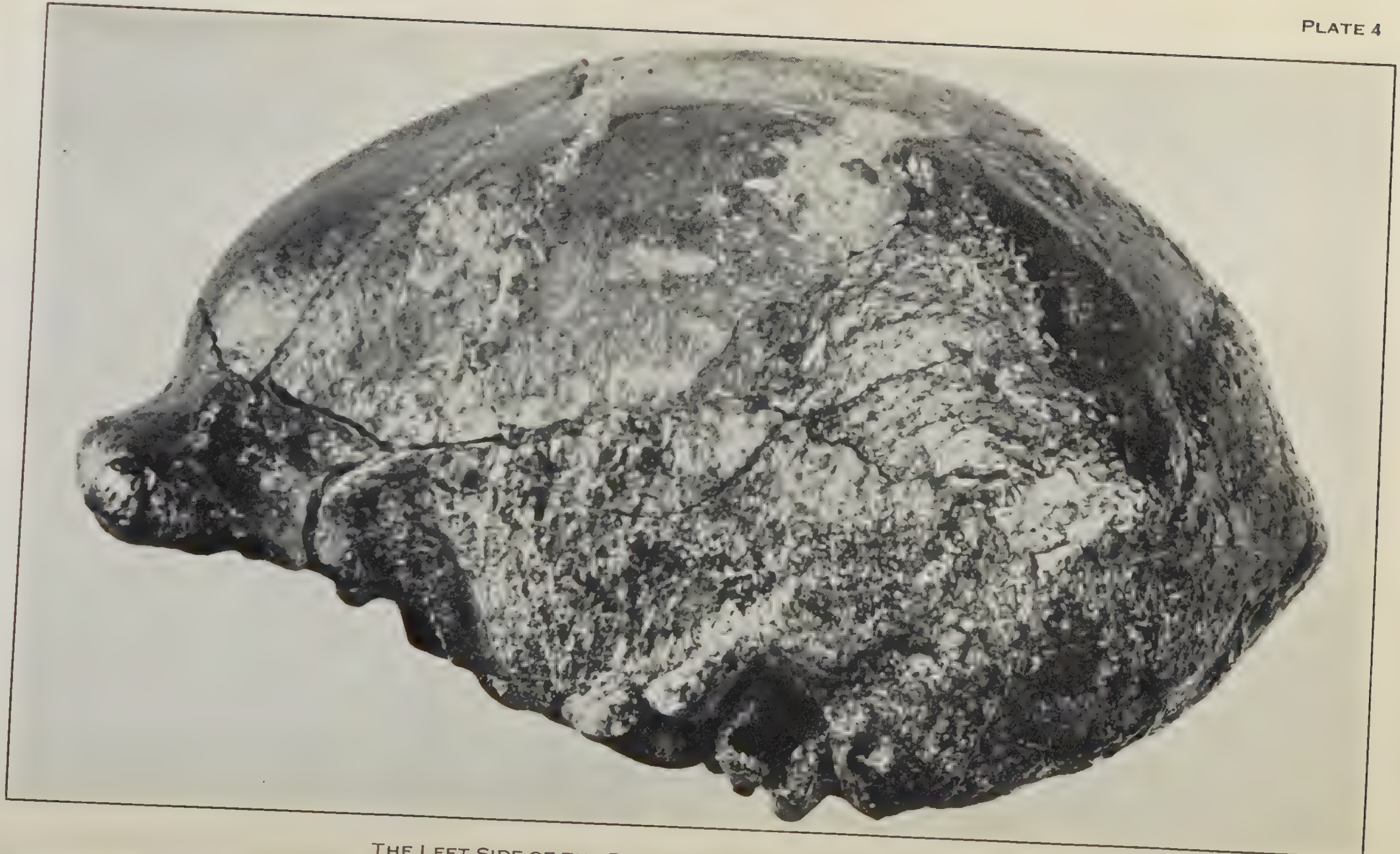
2. POSTERIOR ASPECT OF THE BRAIN CASE

The right and left hand sides of this photograph have been reversed in the engraving.

UPPER SURFACE OF THE PEKING SKULL



UNDER SURFACE OF THE PEKING SKULL BEFORE THE MATRIX WAS REMOVED FROM ITS INTERIOR



THE LEFT SIDE OF THE BRAIN CASE FOUND DECEMBER 2, 1929

1. THE LOWER SURFACE OF THE BRAIN CASE

2. THE UPPER ASPECT OF THE SKULL WITH PART OF THE ROOF REMOVED TO SHOW THE EXCEPTIONAL THICKNESS OF THE SKULL AND THE APPEARANCE OF THE NATURAL LIMESTONE CAST OF THE BRAIN CAVITY

THE SAME SPECIMEN SEEN FROM THE RIGHT SIDE TO DISPLAY IN AN EVEN MORE EMPHATIC WAY THE THICKNESS OF THE SKULL AND THE DIMINUTIVE SIZE OF THE SPACE FOR THE BRAIN

The tooth of a cave bear is imbedded in the limestone cast just behind the edge of the frontal bone.

DR. DAVIDSON BLACK ENGAGED IN REMOVING THE TRAVERTINE MATRIX FROM THE PEKING SKULL

THE PARIETAL BONES OF THE PEKING SKULL (2) COMPARED WITH THOSE OF A MODERN YOUTH (1) OF CORRESPONDING AGE

THE SECOND PEKING SKULL

THE CULTURE OF THE SHANG DYNASTY [1]

By James M. Menzies

THE PERIOD

The Shang Dynasty is the name given by Chinese historians to that line of kings which preceded the Chou.[2] According to the western equivalents of the dates calculated by Ssŭ-ma Ch'ien, the author of the Shih Chi or "Historical Record," the Shang Dynasty lasted from 1766 B. C. to 1122 B. C., or, in other words, for 644 years beginning some 12 centuries before Confucius. These traditional calculations are, however, probably incorrect, and I have provisionally adopted two statements made in the ancient "Bamboo Books," excavated about the year 281 A. D. and dating from the fourth or third century B. C. These state that "from the founding of the Shang Dynasty by Ch'êng T'ang until its destruction by the Chou people was a period of 496 years"; and that "from the time of the moving of the capital by P'an Kêng to the present Waste of Yin until the end of the dynasty, 273 years elapsed." According to the "orthodox" dating of the overthrow of the Shang Dynasty, 1122 B. C. (although some would place it as late as 1050 B. C.), its founding would have occurred in 1618 B. C., and the movement of its capital, just mentioned, in 1395 B. C.

In any case, the Shang period corresponds to that of the Late Bronze Age in the Near East. Within it fall the reigns of the religious reformer Akhenaton and his son-in-law Tutankhamon in Egypt; the occupation of Canaan by the Hebrews; the Minoan Period in Crete; and the Heroic Age in Greece. During its course Babylonia was under the sway of the Kassites; and it was perhaps then that the Aryan invasion of India took place. This historical background will aid us to correlate the Shang period in China with the better known history of the Occident.

THE SOURCES

Let us see now upon what evidence an appraisal of the culture of the Shang Dynasty must be based. Our principal and most author-

[1] Lecture delivered before the North China Union Language School, Peiping, China, on Feb. 6, 1931.

[2] The title which we translate as "emperor" was not assumed by the rulers of China until 221 B. C. Before that date they are properly called kings.

itative source is to be found in the inscribed bones from the Waste of Yin. In 1899 the first of these to attract attention were found 5 li (nearly 2 miles) northwest of the city of Chang-tê Fu, otherwise known as An-yang, in northern Honan. It long remained unknown whence these bones came, although collections of them were made by Chinese antiquarians, among them L'iu T'ieh-yün and Lo Chen-yü. Some specimens, both genuine and forged, were also secured by the Rev. Samuel Couling and Dr. Frank Chalfant, and later by L. C. Hopkins and by Dr. Richard Wilhelm. Certain curio dealers stated that the place of origin of the bones was the tomb of Pi Kan, near Wei-hsien, while others claimed that they came from Yu-li, in T'ang-yin, where Wên Wang was imprisoned.[3] Again, Lo Chen-yü, the well known antiquarian above mentioned, was informed that they were being found at An-yang. No responsible scientist, however, had personally confirmed the place of their origin, and everyone was dependent upon the hearsay reports of dealers.

I first visited the Waste of Yin in the early spring of 1914. The site has nothing about it to attract particular attention, save for the broken potsherds, which the farmers have carefully gathered from the surface of the ground, and which have become buried along the edges of the fields. From 1914 until the present I have carefully collected the many fragments of inscribed bones which have come in my way. The dealers from the cities would purchase only large specimens; small pieces were not wanted. Of these latter I was fortunate enough, in the course of 15 years, to collect many thousands, some no larger than a bean. These fragments have formed the source material for my study. Broken potsherds and stone and bone implements I also found and kept. It was at no time possible, however, to do any excavating. I could only make observations on exposed sections of the soil along the river bank. Unfortunately all my material was destroyed during the disturbances which took place in 1927.

In the autumn of 1928 the Academia Sinica (the scientific branch of the newly established Chinese Government) sent one of its representatives, Tung Tso-pin, to undertake investigations on the site. Early in the following year he was joined by Dr. C. Li, then on the field staff of the Freer Gallery of Art, Washington, D. C., which then undertook the entire cost of the excavation. Work was carried on through the greater part of 1929, and the Academia Sinica has since published two reports (in Chinese), which add considerably to the information which we have been able to extract from the inscribed bones themselves and from the surface finds.

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[3] The date ascribed by the "orthodox" chronology to Wên Wang, the father of the founder of the Chou Dynasty, is 1231–1135 B. C.

It is earnestly to be hoped that the An-yang site will be carefully and scientifically excavated in accordance with the most approved modern methods; for it is the only one thus far known which gives us datable material for a study of the Shang Dynasty. To fail to treat it with the same exactness and care that are being exercised, for example, in the excavations at Ur or Kish in Mesopotamia, or in those of Megiddo or Bethshean in Palestine, would be one of the greatest archeological losses possible, not only to China but to the entire civilized world.

In addition to the inscribed bones, there are certain other literary sources for our interpretation of the culture of the Shang Dynasty. These are to be found, in part, in the very few authentic sections of the earlier part of the *Shu Ching*, or "Book of History." The *P'an Kêng P'ien* and the "Day of Supplementary Sacrifice" are the principal ones. These were re-edited during the Confucian period, and thus are not entirely in their original form. But the most important literary sources that link up with the information yielded by the inscribed bones are the traditions preserved in the ancient "Bamboo Books"; in the "Spring and Autumn Annals" of Lu Pu Wei; in the T'ien Wên P'ien of the Ch'u Elegies; and also in that fabulous wonder-book, the Shan Hai Ching, or "Mountain and Sea Classic."

In our study of the culture of the Shang Dynasty we must always bear in mind that the entire literary history of the period was written under the strict editorial censorship of scholars of the orthodox Confucian school. Many statements in the ancient records not in harmony with their politico-ethical interpretation of life were deleted, as spurious interpolations, and an imaginary Golden Age conforming to their own conception of history was thus manufactured. It is this medley of the true and the false which has created in the minds of all serious students the feeling of the unreliability of early Chinese history. But now that we have available in collections, both those published and others as yet unpublished but accessible to investigators, more than 10,000 readable bone inscriptions, all antedating the Chou dynasty, we have a reliable means of testing the literary and folklore source material.

THE LANGUAGE

Let us now turn to the language as we find it in these documents, which date in the main from the period between P'an Kêng's removal of his capital to the Waste of Yin in 1395 B. C. and a time not long before the overthrow of the Shang Dynasty in 1122 B. C. Within this period of 273 years the forms of the characters show some definite change or development; but we may say that on the whole they remained pictographic throughout; that is, a horse was indicated by the drawing of a horse, a stuck pig by that of a pig pierced a

spear; and so on. But ideographs were also used; thus wei, "to do," is represented by a drawing of a hand guiding an elephant, just as the "mali" guides the elephants piling teak in Rangoon to-day; and nien, "harvest" or "year," is pictured by a farmer bringing in sheaves of grain on his back.

How do we determine the modern equivalents of this ancient script? We have no Rosetta stone such as provided the clue to the ancient hieroglyphics of Egypt. We must restrict ourselves to the Chinese writing itself and trace the development of its characters down through the various periods with the aid of actual archeological evidence. Literary sources can not be trusted except when authenticated by actual remains. Hence we are restricted to the inscriptions on the bones themselves, on bronze vessels, and on stone. Those on the bronzes are very important, and when we have eliminated the forgeries we have a valuable body of source material, such as the San Shih P'an, now in the Old Palace in Peiping and dating from about 860 B. C. Following the bronzes, we have the Han stone monuments, mainly in the official or li script, which show that the characters were first written with a brush and then carved in the stone. From these we may trace the evolution of the Chinese writing down to its present form, which has altered comparatively little since the beginning of the Christian Era. This development during the period from about 1400 B. C. down to the time of Christ has to do mainly with the form of character. But what of its meaning and of its sound? At present I have catalogued all the characters in my own collection of bones and in most of those published by others. For purposes of comparison I am arranging in order all the sentences in which a given character appears, whether on the bones, the bronzes, the early stone monuments, or in the classical literary sources. From such an arrangement of these groups of sentences, sometimes containing a hundred or more examples, it is possible through comparison and a study of the context, largely to fix the meaning of an individual character. In this task the reliance has been very largely on the bone inscriptions, which have thus been used to interpret themselves.

As for the sound attached to the characters in the Shang Dynasty, to my mind this problem is to be attacked by means of the "borrowed characters" (chia chieh), where two characters having the same sound are used interchangeably. In the Shang period it was not uncommon for a simpler character to be substituted for a more intricate one having the same sound. During the official examination period, when the so-called eight-legged essay was in vogue, a man would have been "plucked" for using a character in this way. Starting with this use of homophones and with the rhymes found on the ancient bronze bells and in the Shih Ching or "Book of Odes,"

we have a fruitful source of information regarding the sounds of the ancient Shang Dynasty language.

Let us now turn from the technical interpretation of the latter to some of the more obvious results of its study. First, let us not be misled by the notion that because its script was pictorial, it was therefore in its infancy. That this was not the case is shown at once by the most common characters which it possesses, viz., the numerals and the 22 cyclical characters. These are already conventionalized in many cases. Thus while it is possible to see the reason for the use of the symbols for 1, 2, 3, 4, and 10, I think I am safe in saying that the meaning of the remaining numerals and of the cyclical characters is not obvious, nor is it clear what they portray. This fact indicates that the script was already old and conventionalized and that it had already undergone a long process of development before the fourteenth century B. C.

Secondly, let us not allow ourselves to be carried away with the idea that Chinese writing, simply because of its age, had its origin in Sumeria. In 1929 I visited the sites of Ur and of Kish, in Mesopotamia, and can assure you that the most pictographic scripts found in those two places, dating from before 3000 B. C., are far more conventionalized than is our Chinese script of about 1400 B. C. It is inconceivable that a form of writing already well conventionalized before 3000 B. C. should have retrograded into a more primitive pictographic form 16 centuries later. Such similarities as exist are to be explained by the fact that the minds of the Shang Dynasty Chinese and those of the ancient Sumerians worked in similar ways. Such a book, for example, as C. J. Ball's "Chinese and Sumerian" is so defective on the side of the ancient Chinese script as to be valueless for purposes of comparison.

THE CHINESE PEOPLE BEFORE THE SHANG DYNASTY

As to the origin of the Chinese people and the relationship of the Shang Dynasty culture to the older prehistoric finds from northern China, all that our present knowledge justifies us in saying is that the interval between the Paleolithic Period and the fourteenth century B. C. is so enormous that the two fall into two entirely different and widely separated epochs. We are, however, sure of two very important points. One is, that man did exist in North China in very remote times, so that there is no necessity of introducing him from the West within the historical period. The other point is, that by 1400 B. C. the Chinese people had already developed a very high indigenous culture on the great plain of North China.

Now Dr. J. G. Andersson has found numerous examples of a "painted pottery" ware in various parts of northwestern China,

from Kansu as far east as the village of Yang Shao, in the Province of Honan, just south of the Yellow River. He has dated this material as preceding the culture of the Shang Dynasty, perhaps by as much as a thousand years. And Dr. C. Li reports the finding of a single fragment of this painted ware in a pit which also yielded inscribed bones, at the An-yang site, the "Waste of Yin." On this evidence, he also considers that the "painted pottery" period had its beginning, at least, before the founding of the Shang Dynasty. The pottery of the latter, as found at An-yang, is mainly either of red or gray monochrome or else of that fine incised white ware regarded as especially distinctive of that period. It is to be hoped that a complete excavation of this important site will throw further light on this and other points.

SHANG DYNASTY HISTORY

Over half of the inscriptions on the oracle bones are records of divinations or inquiries by means of the bones themselves, regarding the ancestral sacrifices. In them we find recorded the names of the ancestors to whom sacrifices were to be offered. Often a sacrifice was offered to a number of ancestors in common. On one bone we have mention of a sacrifice to Kao Tsu ("Exalted Ancestor") Wang Hai. Then follow in order three ancestors whose personal name was the cyclical character I: T'ai I, called T'ien I or Ch'êng T'ang (the founder of the dynasty); then Tsu I; and lastly Hsiao I. After these follows Father Ting, by whom is meant Wu Ting, the father of Tsu Kêng. From such oracular records as this we can work out the whole ancestral line of the Shang Dynasty. Not only are the names of its kings given, but so also are those of its queens through whom the succession was passed on to the following generation. It may be asked whether this indicates the existence of a matriarchate. Nothing in the line of descent seems to show this. Women were honored in their character of mothers, just as the matron of Honan to-day is most often referred to as "the mother of So-and-so." Several mothers are often associated with one king's name. Whether these were consecutive or concurrent wives does not appear, although there is no reason to suppose that the Shang Dynasty kings were monogamous. In one respect alone does the mother seem to take precedence in the ancestral sacrifice offered to her by her descendants; when a deceased king and queen receive a sacrifice in common, the rite is always performed on the cyclical birthday of the queen and not of the king.

Succession under the Shang Dynasty was fraternal; that is, the kingly office passed from elder brother to younger brother, and only

after the members of one generation had thus had their turn did it devolve upon a member of the next. What rule was followed in passing from one generation to another, we are not in a position to say. Sometimes the succession went to the son of the eldest brother, and at others to that of the youngest; but in no instance does it appear to have gone to a son of one of the intervening brothers. This type of succession is in marked contrast to that of the succeeding dynasty, that of the Chou, which was from father to son. In the main we may say that the line of descent worked out from the bone inscriptions confirms that recorded for the Shang Dynasty by the Chinese historical books.

THE ORACLE BONES AND THE CLASSICS

The inscribed bones further enable us to interpret certain significant portions of the ancient classics, such, for example, as the genuine document known as "The Day of Supplementary Sacrifice." The orthodox view concerning this was that Tsu Chi was a minister of Kao Tsu Wu Ting, who was offering the supplementary sacrifice to Ch'êng T'ang, the founder of the Dynasty. Now, however, we know from the oracle records that Tsu Chi and Tsu Kêng were brothers, the former being the elder. It was the younger, however, who was offering the supplementary sacrifice to their father Kao Tsu Wu Ting. How is this to be explained? From the bones as well as from tradition preserved in the literary sources, we learn the following story. King Wu Ting had three wives, named respectively Pi Hsin, Pi Wu, and Pi Kuei. By these he had three sons, known to later generations as Tsu Chi, Tsu Kêng, and Tsu Chia. The eldest, Tsu Chi, was a good man; but his mother died young. The mother of Tsu Kêng held the affections of the king, and prevailed on him to pass over Tsu Chi in the succession and place her son Tsu Kêng on the throne. Tsu Chi made no effort to assert his rights, although he was a favorite among the people. Tsu Kêng, feeling insecure on the throne, endeavored to ensure his hold upon it by offering excessive sacrifices to his father Wu Ting. Of all the oracle bones which record the sacrifices of sons to their fathers, those referring to the ones offered by Tsu Kêng to Wu Ting far outnumber all the rest; there are a hundred or more of them.

During one of Tsu Kêng's sacrifices to his father a wild pheasant flew into the ancestral temple, and, attracted by the seething grain in the bronze tripod cauldron, perched on its handle and crowed at the king. The latter was much frightened at this evil omen, and his sage elder brother, whose place on the throne he had usurped, entered and read him a lesson as follows:

The former successful kings
  Were upright, and served the people.
Heaven mirrors the people below,
  Their laws and their just rights,
And sends down harvests in perpetuity,
  Or not in perpetuity.
It is not that Heaven oppresses the people,
  Cutting off its divine decree in the middle,
But that people will not follow goodness,
  Will not listen to their faults.
Heaven has sent forth its decree
  For uprightness and good conduct.
What will you do in regard to it?
  You, O King, must work reverently at caring for your people
And not oppose Heaven,
  Putting at naught the laws of succession and of sacrifice
By excessive rites at the shrine of our father.

Tsu Chi apparently never ascended the throne. He may have died before Tsu Kêng, who was in any case succeeded by the youngest brother, Tsu Chia. The latter sacrificed to his two older brothers together, putting Tsu Chi in his rightful place of honor above Tsu Kêng. The succession passed not through Tsu Kêng, who was so anxious to hold the throne, but through the son of Tsu Chia, K'ang Tsu Ting, who maintained the old tradition of sacrificing to his two deceased uncles, Tsu Chi and Tsu Kêng, as fathers, according to one bone inscription. In another we have Tsu Chi referred to as Hsiao Wang, "Little King," a title which so far as I know does not occur in the literary sources.

Another erroneous orthodox Confucian interpretation of an incident recorded in the Book of History is that of P'an Kêng's moving his capital. This was not from the north to the south of the river, as hitherto believed. Instead, it was from the east, near the birthplace of Confucius in Shantung, across the marshy river system to the Waste of Yin, west of the Yellow River, which then flowed almost due north, a few miles east of the present Peiping-Hankow Railway. This is apparently the reason why he was called P'an Kêng—because he "moved house" (pan chia); for the character for "P'an" is connected with that for pan, a picture of a man poling a boat along a river.

We can not here do more than mention the wars of Wu Ting, and his struggle against the land of Kuei Fang referred to in the I Ching or "Book of Changes"; or to the intermarriage of the daughter of Ti I into the House of Chou. We must also pass over the untangling of many of the cryptic historical references in the I Ching, merely stating that the latter work, the material of which dates back to times long before Wên Wang,[4] seems to be one of

[4] For the date of Wên Wang, or "King Wên," cf. footnote, 3, p. 550.

reference—a sort of key to the type of divination based on the oracle bones. A similar book, recording the historical fulfillment of auguries, was compiled during the Third Dynasty of Ur, in Mesopotamia, about 2500 B. C. There is no reference in the bone inscriptions to that later philosophical concept of the Yin and Yang (the Female and Male Principles in Nature), which appears to form the backbone of the I Ching as we have it to-day. There does seem, however, to be a definite relationship between the six successive divinations, each covering ten consecutive days in the cycle of sixty, and the six continuous and broken lines of the hexagrams. For in both bones and hexagrams, the order is from bottom to top and not the reverse, as one would expect.

THE SHANG RACE BEFORE THE BEGINNING OF THE DYNASTY

The Shang race naturally claimed descent from a long line of ancestors. Allowing 25 years to a generation, we are able to trace the existence of the family back to a period around 2200 B. C. There were undoubtedly other ancestors in the line, and in fact about most of them we have some historical statement in addition to the mere recording of their names. We have no space here to tell of Wang Hai and his troubles with the Yu I, or Ti as they were called in later times.[5] The story is given in part in a verse or two of the T'ien Wên P'ien of the Elegies of Ch'u, as well as in passages in the Shan Hai Ching, and is confirmed by the inscribed bones. Nor can we pause to speak of Hsiang T'u, or of Ti K'u, whose personal name was Chün. It is of interest, however, to note that the name Chün of his Exalted Ancestor (called Kao Tsu Chün) is interpreted in the Shuo Wên dictionary as Mu Hou, or "Mother Monkey," as the character graphically pictures.

THE ART AND MATERIAL CIVILIZATION OF THE SHANG DYNASTY

Let us now turn from the history to the art of the Shang Dynasty. It is a common mistake to confuse the long development of the human race with the period of historic time, or to suppose that the art of Egypt and Mesopotamia, or Crete and India and China, must have been very rude at the time when the written record begins. Nothing is further from the truth. This is shown, in the present connection, by the sculpture of the Shang Dynasty, as exemplified by the torso which Dr. C. Li found at An-yang, and by a broken piece of ivory representing a coiled dragon in my own collection. These are superb in their execution. The jade carvings and bronze castings were magnificent, much excelling the work of any succeeding dynasty down to the present. The incised white pottery already

[5] A group of "barbarian" tribes on the north of the ancient Chinese feudal states which was not thoroughly subdued by the latter until well along in the first millenium, B. C.

mentioned, of which we have now several hundred fragments,[6] has never been excelled in design. And from the bits of shell, ivory, and semiprecious stone evidently once inlaid on wooden objects which have disappeared, as well as from a few examples of bronze and bone where the turquoise still remains, we know that the artists of the Shang period were no less skilled in this type of decorative work. On a plain pottery bowl we find a quality of line hardly later surpassed. So we do also on a bronze vessel, almost certainly of the Shang Dynasty, now in the Museum of Fine Arts at Boston. This, a beautiful wine pail or yin, found 30 years ago near I-chou, the ancient capital of Yen, has an excellence both of design and of material (the latter evidenced by its patination) which is not often exceeded. Last year (1930), while engaged in making rubbings of nearly all the inscribed early bronze vessels in America, I identified this specimen, which was valued only for its intrinsic beauty and not for its historical importance. This vessel and likewise the inscribed bronze halberds found near the Lai Shui [7] suggest that the Shang culture extended as far north as I-chou, not far from Peiping.

Now in contrast note the crude design of the most important bronze of the Chou Dynasty which followed the Shang, that known as the Mao Kung Ting. Its inscription is so significant that had Confucius known of it, declares the scholar Wang Kuo-wei, he would have included it in that compilation of official records known as the Shu Ching, or "Book of History." Surely the recording of such an important inscription on a vessel of so poor a design marks a distinct decline in the art appreciation of the early rulers of the Chou Dynasty in comparison with those of the Shang who preceded them.

Occidental museums and authorities unite in refusing to allow any bronzes to be labeled "Shang," and unfortunately the Palace Museum here in Peiping has followed suit. But the Shang Dynasty was, we know, prolific in its art; and I am convinced that many of our existing bronzes belong to that period. On a fragment of inscribed bone which dates from the time of Tsu Kêng are two important statements: One which mentions the honorable (or valuable) tripod of Wu Ting; and another which speaks of writing on bamboo tablets. Here we have proof that not only were costly sacrificial vessels in existence in the time of King Wu Ting, but also that at that period, in addition to the oracle records on bone, there were also other writings, on slips of bamboo, which, however, have unfortunately not been preserved.

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[6] No entire vessel appears ever to have been found.

[7] A small stream in the province of Hopei (that in which Peiping is situated).

TOTEM POLES: A RECENT NATIVE ART OF THE NORTH-WEST COAST OF AMERICA [1]

By Marius Barbeau

National Museum of Canada

[With 6 plates]

The totem poles of British Columbia and Alaska on the northwest coast of North America have long since achieved world-wide repute. Their decorative style at its best is unique and so effective that it is nowhere surpassed in excellence among the other forms of aboriginal art at large. They express native personality and craftsmanship in terms impressive and intriguing. The museums of Europe and America treasure a number of them, principally from the Queen Charlotte Islands; some adorn the parks of our western cities. These picturesque creations, however, can be seen to full advantage only in their true home, at the edge of the ocean, amid tall cedars and hemlocks, and in the shadow of lofty mountains. With their bold profiles, reminiscent of Asiatic divinities and monsters, they conjure impressions strangely un-American in their surroundings of luxuriant dark-green vegetation under skies of bluish mist.

The art of carving poles belongs to the past. Racial customs and stamina are on the wane everywhere, even in their former strongholds. Totem poles are no longer made. Many of them have fallen from old age, decayed, and disappeared. Some were sold, others removed in maritime raids without the consent or knowledge of the owners. Quite a few were destroyed by the owners themselves during hysterical revivals under a spurious banner of Christianity; for instance the poles of two Tsimsyan tribes, in the winters of 1917 and 1918, at Gitlarhdamks and Port Simpson near the Alaskan frontier.

Not even a remnant of the famous clusters of former days remains among the Haidas of the Queen Charlotte Islands. Barely a few are still left among the Bellacoolas, the Kwakiutl, and the Nootkas of the west coast of British Columbia; in a few years these will have totally disappeared.

[1] Reprinted by permission from the Geographical Review, vol. 20, No. 2, April, 1930.

The only collection of poles that still remains fairly complete is that of the upper Skeena, in British Columbia, a short distance southeast of the Alaskan border, from 150 to 250 miles inland, at the edge of the area where this art is practiced. Nowhere else but on the Nass, where a number of poles also survive, are they to be seen far inland. The Canadian Government and the Canadian National Railways a few years ago inaugurated the policy of preserving the Skeena River poles in their original location. And the Department of Education of the American Government is also restoring some of the Tlingit poles of the Alaskan coast.

FIGURE 1.—The Nass and Skeena River Basins

Well known as is this striking form of native art, one is apt to suppose that our enthnographic literature is well supplied with data on their features and history. The supposition, however, is unjustified. Casual descriptions of poles or models of poles have been furnished by Doctor Swanton, Lieutenant Emmons, Doctor Boas, Doctor Newcombe, and others; but their notes usually appear without the necessary historical context. It is too late now to recover much of this knowledge. The present writer made a complete study of the poles of the three Tsimsyan nations, while engaged in several

ethnographic explorations on the northwest coast for the National Museum of Canada from 1914 to 1927; and a summary of his conclusions is here presented.[2]

SIGNIFICANCE OF THE TOTEM POLE

The characteristic figures on totem poles consist of symbols comparable to heraldic devices—not pagan gods or demons, as is often supposed. They usually illustrate myths or tribal traditions. They were never worshiped; and if they were held sacred, it was only because of their implications.

Those of the Tsimsyan and the Tlingit in particular—and the same thing is also largely true of the Haida poles—were monuments erected by the various families in the tribe to commemorate the dead. In intent they were the equivalent of our tombstones. Indeed, the natives now have some of their crests carved out of stone or marble at Port Simpson or Vancouver and place them as tombstones in their modern graveyards. The owners' object in thus showing their coat of arms was to publish at large their claims to vested rights and privileges. The emblems or totems varied with each family; they were their exclusive property and jealously guarded. They picturized legends, phenomena, and the animals of the country. The eagle, the raven, the frog, the finback whale, the grizzly bear, the wolf, the thunderbird, and many others are among the most familiar themes. Others less frequently seen appear to be more recent: for instance the owl, the salmon, the woodpecker, the beaver, the starfish, the shark, the halibut, the bullhead, the split person, the mountain goat, the puma, the moon, the stars, and the rainbow. These symbols in the last resort were property marks.

The legendary origin of the emblems is explained in traditional narratives that used to be recited in the winter festivals or potlatch. They are still remembered by the members of the older generation, in spite of the decay of tribal customs. They recount how the ancestors long ago met with tribulations and adventures; how they were harassed or rescued by spirits and monsters of the unseen regions; how benevolent spirits appeared in visions and invested their protégés with charms; and how ancient warriors conquered their enemies. The carved illustrations of the stories served a definite purpose, besides those of commemoration and ownership; they made familiar the legends and recollections of the past to all in tribal life.

Soon after the death of a chief his prospective heirs appointed his leading nephew to his post. His induction took place in the

[2] Published with the approval of the Director at the National Museum of Canada.

midst of a large number of invited guests during elaborate festivals, where liberality was an outstanding feature. The name of the uncle passed on to his nephew, and the erection of a totem pole crowned the event. Groups of related families mustered all available resources to make the feast memorable, as their standing and influence depended exactly on their resources thus advantageously displayed.

MAKING AND ERECTING A POLE

The labor of cutting a large red cedar tree, hauling it overland or on the sea for a considerable distance, carving it, and erecting it often took years. The owners required sufficient time to gather their resources and proceeded with expenditures in installments, as it were. A tree was first selected and felled. The allies of the family interested took charge of the work—no relative could accept the stipend. They were fed and paid publicly at the conclusion. A carver was then hired also from among the allies. Should he lack the required skill, it was his privilege to appoint a substitute, over whom he stood ceremonially, assuming the credit of the work for himself. The carving was accomplished as secretly as possible, the figures being selected by the owners from their list of available crests, which often exceeded the fingers of one hand in number. Far more costly was the actual planting of the pole in the ground. When enough food and wealth were amassed, invitations were sent forth to all the leading families of the neighboring tribes; and the pole was erected in the presence or with the help of the hundreds of people gathered in festivities that were the corner stone of social life until about 40 years ago.

These carved memorials as a rule face the water front, and the rivers or the ocean were the main highways. They stand apart from one another, in front of the owners' houses, and dot the whole length of the village in an irregular line. In recent years the villages have been moved to new sites, and the poles seem forsaken in the deserted abodes of the past. Trees have grown up around them in several places, and it is difficult to find them—particularly along the Nass.

DEVELOPMENT OF THE ART OF THE TOTEM POLE

Enough material has been retrieved from oblivion for a detailed history of Tsimsyan plastic art and the making of totem poles. Our study covers over 150 such memorials. The villages of the upper Skeena are the only ones that still retain some of their earlier barbaric features. Kispayaks, Gitsegyukla, and Kitwanga each claim about 20 poles. Gitwinlkul now is the most remarkable of all the tribal villages. It stands on the Grease Trail from the Skeena to the Nass, claiming the largest number of poles now standing anywhere in a

single cluster—about 30 in all. It is impressive. Its poles are among the tallest and best; they are also the oldest.

It is evident that the carving of the poles was a truly popular art. If some artists were at times preferred to others for their skill, their choice for specific tasks was governed by customs largely unconcerned with craftsmanship. Each family of standing had every inducement to resort to its own carvers for important functions in ceremonial life. We have statistical evidence of this. The hundred totem poles of the upper Skeena were produced by more than 30 local carvers and 13 foreigners. Six of the foreigners were from the Nass, and they had been engaged in the earliest period when the Skeena artists were not yet proficient in the new calling; 3 others were from the lower Skeena, and 4 from the Bulkley River, a tributary of the Skeena. The Skeena carvers belonged to independent and widely scattered social groups or families; that is 23 of them were of the Raven-Frog phratry; 9 of the Wolf, 5 of the Eagle, and 3 of the Fireweed. Seventy-eight out of the hundred poles are ascribed to Gitksan artists, while the rest are credited to foreigners.

The art of carving and erecting memorial columns is not really as ancient on the northwest coast as is generally believed. Popular misconceptions that totem poles are hundreds of years old are fantastic. They could not be, from the nature of the materials and the climatic conditions. A green cedar can not stand upright much longer than 50 or 60 years on the upper Skeena, where precipitation is moderate and the soil usually consists of gravel and sand. Along the coast it can not endure the intense moisture that prevails most of the year and the muskeg foundation much more than 40 years. The totem poles of Port Simpson, for instance, all decayed on the south side first, which is exposed to warm rainy winds. Most of the well-known poles now in our parks and museums were carved after 1860, while not a few of those seen in Indian villages, such as Alert Bay, were erected after 1890.

The growth of native technique to its present state is largely confined to the past century. It hinged upon European tools—the steel ax, the adze, and the curved knife—which were traded off in large numbers to the natives from the days of the early circumnavigators—that is after 1778. The lack of suitable tools, of wealth, and of leisure in the prehistoric period precluded the elaboration of ambitious structures and displays. The benefits accruing from the fur trade at once stimulated local ambitions; they stirred up jealousies and rivalries and incited incredible efforts for higher prestige and leadership. The totem pole came into fashion after 1830 through the rise of these ambitions. The size of the pole and the beauty of its figures published abroad the fame of those it represented.

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Feuds over the size of poles at times broke out between semi-independent leaders within a village. The bitter quarrel between Hladerh and Sispegoot, on the Nass, will not soon be forgotten. Hladerh, head chief of the Wolves, would not allow the erection of any pole that exceeded his own in height. Sispegoot, head chief of the Finback Whales, could afford to disregard his rival's jealousy. When his new pole was carved, more than 60 years ago, the news went out that it would be the tallest in the village. In spite of Hladerh's repeated warnings, Sispegoot issued invitations for its erection. But he was shot and wounded by Hladerh as he passed in front of his house in a canoe. The festival was perforce postponed for a year. Meanwhile Hladerh managed, through a clever plot, to have Sispegoot murdered by one of his own subordinates. He later compelled another chief of his own phratry, much to his humiliation, to shorten his pole twice after it was erected; and he was effectively checked only when he tried to spread his rule abroad to an upper Nass village.

The present crop of poles is the first of its kind to stand on the Skeena, with the exception of a few of the oldest that have already fallen and decayed. The oldest poles of Gitsegyukla (at Skeena Crossing) have stood only since the fire destroyed the earlier village in 1872; those of Hazelton were carved after the establishment of the Indian reserve about 1892. But several of the poles in the other villages—including Kitwanga—are many years older; they are particularly interesting, as they illustrate the growth of totem pole carving within two or three generations in the nineteenth century.

Most of the poles of the upper Skeena were erected in the past 40 or 50 years. The oldest five or six may slightly exceed 70 years of age. Not a few are less than 30 years old. It is safe to say that this feature of native life among the Gitksan became fashionable only after 1870 and 1880. Only 6 out of nearly 30 poles at Gitwinlkul—the earliest of these villages to adopt the art—exceed 50 years of age; and only a few poles at that time stood in the neighboring villages.

TECHNIQUE AND ITS EVOLUTION

Native accounts and the evidence of the carved memorials lead to the conclusion that, among the Tsimsyan, carved house-front poles and house-corner posts were introduced first, many years before the first detached columns appeared. Several houses and posts of this kind are still remembered by the elders and have been described; a few are still to be observed, particularly at the lower canyon of the Skeena, though most of them are in an advanced state of decay. The archaic style of house decoration was abandoned as soon as the

natives gave up building large communal lodges in the purely native manner, and memorial columns that could no longer serve as ceremonial doorways, or traps, became the new fashion. Some of the upper Skeena villages, indeed, never adopted the fashion wholesale; at least four of them boasted of no more than a few poles, and part of these were put up only after 1890.

Internal evidence tells the same tale. The technique of carving on several of the oldest poles on the upper Skeena discloses anterior stages in the art. It is essentially the technique of making masks or of carving small detached objects; or, again, of representing masked and costumed performers as they appeared in festivals rather than the real animals or objects as they exist in nature. These early Skeena River carvers had not yet acquired the skill of their Nass River masters, who had advanced to the point of thinking of a large pole as an architectural unit that called for harmony of decorative treatment.

Haesem-hliyawn and Hlamee, of Gitwinlkul, represent distinctive periods of the craft among the Gitksan. To Haesem-hliyawn goes the credit of carving some of the best poles in existence. He lived as late as 1868, while Hlamee, his junior and follower, died after 1900.

The style of Haesem-hliyawn was of the finest, in the purely native vein. He combined a keen sense of realism with a fondness for decorative treatment. His art sought inspiration in nature, while maintaining itself within the frontiers of ancient stylistic technique. Haesem-hliyawn belonged to the generation wherein the totem pole art was still in its growth (1840–1880) and all at once reached its apogee. His handling of human figures counts among the outstanding achievements of west coast art—indeed, of aboriginal art in any part of the world. The faces he carved, with their pronounced expression and amusing contortions, are characteristic of the race.

Hlamee, a prolific worker, introduced the white man's paint to enhance the features of his carvings. While he used paint with discretion and to good effect, it immediately lessened the sculptural quality of the work. The new fashion did not compensate for the evident loss of native inspiration and artistry.

The carved poles of the Nass maintain a much higher average standard of art than those of the Skeena; but they are less numerous, for the reason that the Nass people gave up their ancient customs much earlier than the Kitksan—that is 40 or 50 years ago. The technique of pole carving in both areas represents well the passage from the earlier and better art of the Haesem-hliyawn type to that of Hlamee.

The Tsimsyan of the lower Skeena, on the other hand, never were devoted to the art of carving totem poles. When they were moved

long ago to commemorate a historical event of first magnitude, they erected a tall slab of stone. If the Tsimsyan proper as a body were not swayed by the modern fashion of erecting carved memorials to their dead, they retained until fairly late the older custom of painting in native pigments their heraldic symbols on the front of their houses. While not a single totem pole seems ever to have stood in the village of Gitsees, near the mouth of the Skeena, five house-front paintings were still clearly remembered and described a few years ago. And it was related that many houses in the neighboring tribes were decorated in this style, which at one time may have been fairly general along the coast.

The remarkable west coast custom of carving and erecting house poles and tall mortuary columns or of painting coats of arms on house fronts is sufficiently uniform in type to suggest that it originated in a single center and thence spread outward in various directions. The limits of its distributions coincide with those of the west coast art proper which embrace the carving or painting of wood, leather, stone, bone, and ivory.

This art itself seems much more ancient in some of its smaller forms than in its larger ones. Its origin on the northwest coast is remote. It goes back to prehistoric times. It was already in existence and fully mature and quite as conventionalized as it is today at the time of the early Spanish, English, and French explorers (1775–1800). Most of the early circumnavigators—Cook, Dixon, Meares, Vancouver, Marchand, and La Pérouse—give ample evidence that masks, chests, ceremonial objects were at the end of the last century decorated in the style now familiar to us. They also mention that house fronts were decorated with painted designs. There is, however, a striking lack of evidence everywhere as to the existence of totem poles proper or detached memorial columns, either south or north. For instance, Dixon examined several of the Haida villages on the Queen Charlotte Islands; but he fails to mention totem or even house poles, even though he minutely described small carved trays and spoons.

But there were already, from 1780 to 1800, some carved house posts in existence. Captain Cook [3] observed a few carved posts inside the house of some chiefs at Nootka Sound, where he wintered in 1780; and Webster, his artist, reproduced the features of two of them in his sketches. Meares, in 1788 and 1789, observed like Nootka carvings in the same neighborhood, which he describes thus: "Three enormous trees, rudely carved and painted, formed the rafters, which were supported at the ends and in the middle by gigantic images,

[3] Cook, James, A voyage to the Pacific Ocean, vol. 2, p. 317. 3 vols., London, 1784.

carved out of huge blocks of timber."[4] And he calls them elsewhere "misshapen figures." The earliest drawing of a carved pole is that of a house frontal or entrance pole (not a real totem pole) of the Haidas; and it is found in Bartlett's Journal, 1790.[5]

ORIGIN OF THE TOTEM POLE ART

The custom of carving and erecting mortuary columns to honor the dead is therefore modern, that is post-Columbian; it may exceed slightly the span of the last century. In spite of this, it is not easy to trace back its origin to its very birthplace. Even the simple poles of the Nootkas as described by Cook are not likely in themselves to represent a form of native art of the stone age in its purely aboriginal state, undisturbed by foreign influences. Iron and copper tools at that date were already in the possession of the natives; and they were used everywhere as only they could be by expert craftsmen through lifelong habit. The west coast at that date was no longer unchanged. The Russians had discovered it many decades before, and the Spanish had left more recent traces of their passage. Moreover, the influence of the French and the English had crossed the continent through contacts between intermediate tribes and the arrival of halfbreeds and coureurs de bois west of the mountain passes. From our records of exploration and adventure it appears certain that the northwest coast people were accessible to foreign influence for more than 200 years, to say the least. The natives themselves were highly amenable to foreign influence. Nowhere in America did they show more avidity or greater skill to acquire and utilize from the sundry goods and crafts of the white man whatever suited their needs.

Precisely where the totem poles, or mortuary columns, first appeared and at exactly what moment is an interesting though elusive, point. Our evidence eliminates the Gitksan, or the Tsimsyan proper, from among the possibilities. Evidence abundantly shows that the Nass River tribes made totem poles at an earlier period than the upper Skeena people. Many families on both sides are mutually related. Several of the Gitwinlkul villagers have their hunting grounds on the upper Nass; and the Gitksan used to travel every spring to the lower Nass for eulachan fishing or to trade pelts or dried fruit cakes with the coast tribes. In the course of time a strong cultural influence from the more progressive tribes of the coast thus resulted.

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[4] Meares, John, Voyages made in the years 1788 and 1789, from China to the North West Coast of America, p. 138, London, 1790.

[5] Cf. The Sea, the Ship, and the Sailor: Tales of Adventure, etc., with an introduction by Capt. Elliot Snow, Salem, Mass., 1925.

Likewise the tribes farther south can not be considered. The Bellabellas were painters rather than carvers. The Kwakiutl and the Nootka plastic art always remained very crude compared with that of the northern nations; and, besides, it reveled in grotesque forms by preference. It seldom was at the service of heraldry as in the north, heraldry being of minor import on the coast south of the Skeena. Totem poles among the Kwakiutl and the Nootka are all very recent; not many of them, as they are currently known, may antedate 1880. The most familiar of the Kwakiutl poles, those of Alert Bay, were all carved and erected since 1890. None of them stood at the time when the late C. F. Newcombe visited the village at that date.

At first sight it seems more likely that the Tlingit, of the southern Alaskan frontier, might have initiated the custom of erecting memorials to the dead. They were closer to the Russian headquarters and must have been among the first to obtain iron tools. There is no doubt, besides, that they were most skillful carvers and weavers, through the whole local evolution of these crafts. Yet there are good reasons why the credit for originating totem poles should not fall to their lot. The early circumnavigators that called at some of their villages made no mention of large carvings that we know, not even of such house or grave posts as they observed among the Haidas farther south. From a keen and experienced observer of these people, Lieut. G. T. Emmons, who was stationed on the Alaskan coast for many years in an official capacity, we learn that the northern half of the Tlingit nation never had totem poles until very recently; and the few of those that have sprung up in that district within the scope of his observation are the property of a family or families that originally belonged to the southern tribes and have retained their southern affiliations.

The Haidas must next be dismissed from consideration as likely originators of the art. The Haida poles, as we know them, are partly house poles and partly totem poles proper; the former far more numerous proportionally than among the Tsimsyan. Indeed, almost none of the present Nass River carvings were house poles. The two large posts observed among the Haidas by Bartlett and Marchand in 1788–1792 were house portals. Though the Haida villages were often visited at the end of the eighteenth century and in the first part of the nineteenth, we find no other reference to large poles, still less to the famous rows of poles at Massett and Skidegate as they were photographed about 1880. The Haida poles as we know them in our museums are all of the same advanced type of conventionalism, all of the same period, that is 1830–1880, and presumably all from the hands of carvers that were contemporaries. They were from 10

to 30 years old when the Haidas became converts to Christianity and in consequence gave up their customs, cut down their poles, and sold them to white people about the year 1890 or afterwards. It is a common saying, however inaccurate it may be, that the fine row of poles in one of their best-known towns had risen from the proceeds of an inglorious type of barter in Victoria. There is no evidence of mortuary poles among the Haidas antedating 1840 or 1850, though a few earlier and transitional ones may have served to introduce the fashion.

The probabilities are that totem poles proper originated among the Nisrae or northern Tsimsyan of the Nass River. It is evident, from traditional recollections, that the custom of thus commemorating the dead is not very ancient among them; yet it certainly antedated that of the Gitksan or the Tsimsyan. It is far more likely that the Haidas and the Tlingit imitated them than the reverse. The estuary of the Nass was the most important thoroughfare of Indian life in all the northern parts. Eulachan fishing in the neighborhood of what is now called Fishery Bay near Gitrhateen, the largest Nisrae center, was a dominant feature in native life. The grease from the eulachan, or candlefish, was a fairly universal and indispensable staple along the coast. For the purpose of securing their supply of it the Haidas, the Tlingit, the Tsimsyan, and the Gitksan traveled over the sea or the inland trails every spring and camped in several temporary villages of their own from Red Bluffs eastwards on the lower Nass, side by side, for weeks at a time. During these yearly seasons exchanges of all kinds—barter, social amenities, or feuds—were quite normal. As a result, cultural features of the local hosts—whether they were willing hosts or not is an open question—were constantly under the observation of the strangers and were often a cause for envy or aggression. It is doubtful, on the other hand, whether the Tsimsyan ever traveled to the Queen Charlotte Islands or the Tlingit country unless to make a raid or an occasional visit to relatives.

It is agreed among specialists that the Nass River carvers were on the whole the best in the country. Their art reached the highest point of development ever attained on the northwest coast. And their totem poles—more than 20 of which can still be observed in their original location—are the best and among the tallest seen anywhere. The Haida poles are stilted, conventional, and offer little variety in comparison. It is noteworthy, besides, that the Tlingit poles resemble in character those of the Nass River. And the Nisrae assert that a number of totem poles at Tongas (Cape Fox), the southernmost of the Tlingit villages, were the work of their carvers within the memory of the passing generation.

The close similarities between the plastic arts of the northwest coast and those of the various people around the edges of the Pacific Ocean should not be overlooked. Common features in the art and technology of our coast natives and the Polynesians, for instance, are too persistently alike in some aspects to be unrelated, at least in some remote way. The early navigators noticed, about 1780–1790, the striking resemblance between the fortresses of the Haidas and other coast tribes and the "hippah" of the New Zealand natives. Totem poles, as fairly recently carved and erected on both sides of the Pacific, offer the same compelling resemblance. Their technique of erection, besides, was identical. It will gradually become an established conclusion, we believe, that much of the growth of native crafts in wood carving and decoration as now exemplified in the museums of the world is far more recent than is generally believed.

1. THE MOUTH OF THE NASS RIVER NEAR PORTLAND CANAL

2. GITWINLKUL, A GITKSAN VILLAGE OF THE GREASE TRAIL BETWEEN THE NASS AND THE SKEENA, SUMMER OF 1924

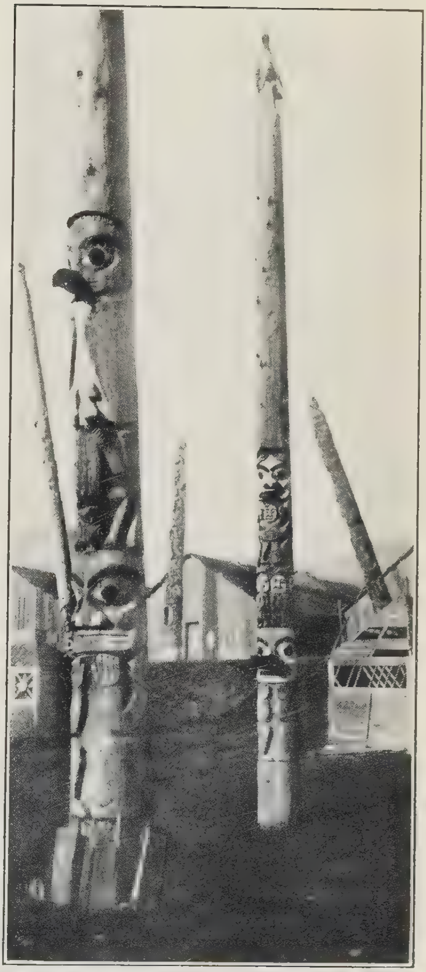
Writer's camp in the foreground.

1. TWO POLES AT KISPAYAKS, SKEENA RIVER, ERECTED AT 20 YEARS' INTERVAL IN MEMORY OF TWO SUCCESSIVE CHIEFS

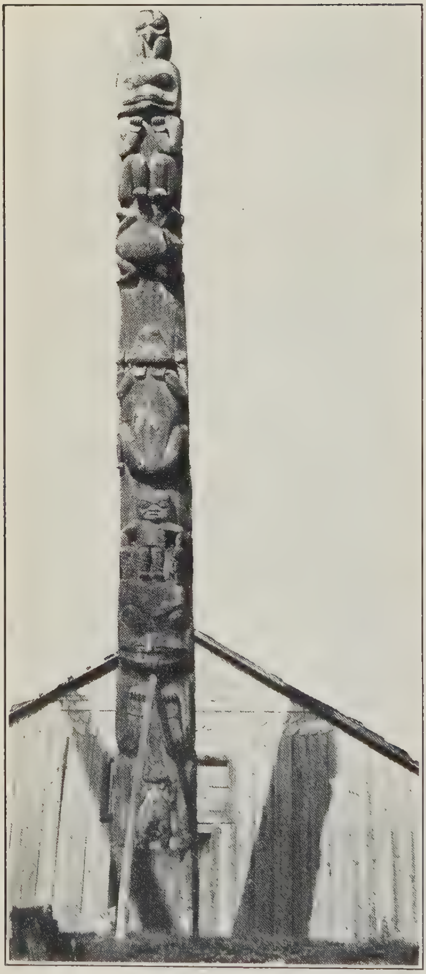
2. THE POLE OF TRALARHAET, A BEAVER-HALIBUT CLAN OF THE EAGLE PHRATRY, AT GITIKS, NASS RIVER

The crests illustrate the myth of a migration southward of the owners.

1. TOTEM POLES AT GITWINLKUL, CARVED BY HAESEM-HLIYAWN, A LEADING CARVER ABOUT 50 YEARS AGO



2. TOTEM POLES AT GITWINLKUL, CARVED BY HLAMEE, A LATTER-DAY FOLLOWER OF HAESEM-HLIYAWN



1. ONE OF THE OLDEST AND FINEST POLES IN EXISTENCE, AT GITWINLKUL

This was formerly a house-front portal, the ceremonial entrance being through the opening at the bottom.

2. ONE OF THE FINEST OLD POLES AT ANGYEDERH ON THE LOWER NASS

1. AN EAGLE POLE AT GITIKS, THE FORMER NASS RIVER VILLAGE NEAREST TO THE ALASKAN BORDER

This is one of the finest and tallest poles in existence.

2. TOTEM POLES AT KITWANGA (THE RABBIT TRIBE), ON THE UPPER SKEENA

The nearest pole—that of the Ensnared grizzly—counts among the finest. It was carved by Haesen-hliyawn about 60 years ago.

1. MENESK, THE EAGLE HEAD CHIEF OF GITLARDAMKS, ON THE UPPER NASS

His carved headdress and old Chilkat robe are among the finest and most valuable of the kind.

2. SEMEDEEK, AN OLD EAGLE CHIEF OF KITWANGA, ON THE UPPER SKEENA

His headdress shows his Eagle crest. His robe is a Chilkat.

BROBDINGNAGIAN BRIDGES[1]

By Othmar H. Ammann

[With 7 plates]

A hundred years ago it was predicted that the famous bridge across the Menai Straits in England, with a span of 570 feet, would forever constitute a world wonder. Only 50 years later that maximum length of span was more than doubled and the suspended mass increased tenfold in the Brooklyn Bridge across the East River in New York. And if we compare Brooklyn Bridge, which 50 years ago was by far the most outstanding engineering work of its kind, with the George Washington Bridge in New York now nearing completion, we find that the span length in the last 50 years has been again more than doubled, the traffic capacity multiplied at least four times, and the total mass suspended over the river more than eight times.

It is also of interest to note that in spite of this enormous increase in the mass and quantity of material in the George Washington Bridge, the time of construction will be less than one-half that consumed by the Brooklyn Bridge, and that the total cost, in proper consideration of the depreciation of the purchase value of money, will be less than twice that consumed by the much smaller Brooklyn Bridge. These results have, of course, been made possible only by the far-reaching developments in other technical lines, such as mechanical and electrical engineering, and metallurgy, as well as in the field of theory and experiment.

From the engineering or technical point of view, progress in bridge construction manifests itself in improved types and forms of construction and details, in better and stronger materials, in more accurate and cheaper shopwork, and in more expeditious and safer erection, all of which are essential for the construction of larger bridges. It is principally along these lines that I desire to illustrate progress made in recent years.

TYPES OF BRIDGES

The selection of the type or form of bridge to be used for any particular crossing is, from the engineering point of view, one of the

[1] Reprinted by permission from the Technology Review, vol. 33, No. 9, July, 1931.

most important factors in the construction of large bridges, and is a question which has often led to animated discussions and differences of opinions in the profession. It is a question which depends upon many different factors and not in the least upon the personal conceptions of the designer.

At the beginning of this century and up to as late as the World War, two types of bridges appeared to be particularly favored, although they are generally the least satisfactory from the esthetic point of view: the cantilever bridge for the longer spans and the simple span truss type for the lesser span lengths of up to 700 feet. The most outstanding example of the former type is the Quebec Bridge across the St. Lawrence River with a main span of 1,800 feet, which until recently has been the longest span in existence. The longest simple span is that of the bridge across the Mississippi at Metropolis with a length of 720 feet (pl. 5, fig. 2).

Many bridges of the cantilever type have been built across the Ohio, Mississippi, and other wide streams. To the most recent and typical examples belong the two bridges built by the Port of New York Authority across the Arthur Kill in New York. The type is particularly suitable where foundation conditions make other types expensive or subject to the effect of possible settlements. But its merits, particularly the alleged advantage of its being statically determinate, have been overrated.

For a long period there existed a very general prejudice against the so-called continuous truss, so much so that, in spite of its economic advantages, it was practically excluded from consideration in favor of the simple truss or the cantilever. Its application in 1916 in the bridge across the Ohio at Sciotoville with two spans of 775 feet each marked a revival of that meritorious type and it has since been employed in quite a number of bridges (pl. 4, fig. 1).

Less frequently, and only under favorable circumstances, such as the presence of rocky abutments to resist its thrust, has the arch type been used. Until the present the famous Hell Gate Bridge, completed in 1917, across the East River in New York with a span of nearly 1,000 feet has been the most outstanding example, but it is now being outranked by two bridges, both now nearing completion; namely, that across the entrance to Sydney Harbor in Australia with a span of 1,650 feet, and that across the Kill van Kull in New York with a span of 1,675 feet.

The suspension bridge is the type eminently suited for long spans and is now recognized as the only one to be considered for very long spans. The true nature of this naturally graceful type has long been misunderstood and it is only very recently that it

has begun to regain the prominent position which it occupied in the early part of the nineteenth century. A large number of bridges of this type, particularly for highway and combined highway and rapid transit rail traffic, have been built in the last 10 or 15 years, even with moderate spans, and its greatest length of span has been continuously leaping to new records.

The Manhattan Bridge in New York with a span of 1,470 feet was the most outstanding modern suspension bridge only 10 years ago. Since then there followed in rapid succession the Bear Mountain Bridge across the Hudson with a 1,630-foot span, the Delaware River Bridge in Philadelphia with 1,750 feet, the Detroit River Bridge with 1,850 feet and now the George Washington Bridge nearing completion with 3,500 feet. And a start has been made on the Golden Gate Bridge in San Francisco with a span of 4,200 feet.

A factor which, I believe, has very materially contributed to the revival of the suspension bridge, is the changed conception regarding the proportioning of the so-called stiffening system of this type. As a result of the insufficient rigidity of many of the early light and short suspension bridges it became a general practice here and abroad to proportion suspension systems as rigid systems, such as the truss or the upright arch. This theory leads to enormous waste of material in long-span suspension bridges, more particularly those bridges carrying highway or mixed highway and rail traffic, because it does not take into consideration the stiffening effect of the large suspended mass, compared to the relatively much smaller load units which cause the span to sag or oscillate. Conspicuous stiffening systems also give an unsightly, clumsy appearance to such bridges and destroy the gracefulness of the cables hanging in their natural catenary.

To-day the justification of a flexible, more economical, and more graceful stiffening system in long and heavy suspension bridges is generally recognized. Studies made in connection with the George Washington Bridge indicated that such a long span of 3,500 feet, with comparatively short side spans, designed to carry vehicular and rapid transit traffic, required practically no stiffening of the freely suspended cables. Accordingly, the bridge was designed and is being built without any stiffening whatsoever in its initial stage, in which only the upper deck for highway traffic will be in place. When the lower deck for rapid transit rail traffic is added, it will have comparatively flexible, very light stiffening trusses between the two decks.

When it is considered that in such a long span every pound of steel unnecessarily applied for stiffening is merely ballast, and that this pound of useless material requires the use of another pound of material in the cables, towers, and anchorages it may be realized that such wasteful proportioning involves millions of dollars.

QUALITY OF MATERIALS

An important phase in the development of long span bridge building is the improvement of the materials, more particularly the introduction of so-called high strength alloy steels, for high strength material does not only effect a reduction in the dead weight which in large bridges may mean a saving of millions of dollars, but it makes possible certain structural members and connections of large proportions which would be impracticable with ordinary steel. For riveted members and connections a medium hard structural steel of from 55,000 to 70,000 pounds per square inch is still generally used for ordinary bridges.

About 25 years ago nickel steel, which has a strength of about 50 per cent greater than the ordinary steel, was introduced and found increasing application in large bridges, as for instance in the Quebec Cantilever Bridge, in the stiffening trusses of the Manhattan Bridge, and also in a number of long simple span trusses.

During and after the World War silicon steel entered the field in sharp competition with nickel steel. Its strength is about 40 per cent greater than ordinary steel or about 7 per cent less than nickel steel, but it can be manufactured at a materially smaller cost than the latter. In fact, its cost has now been so reduced that it can be used economically even in bridges of medium size in place of ordinary steel. The towers and floor structure of the George Washington Bridge are built almost entirely of silicon steel.

In the case of the Bayonne Bridge with its exceptional span of 1,675 feet, manganese steel was introduced for the heavy main arch ribs. Its strength is equivalent to that of nickel steel, but its price was slightly less. In this same bridge there was also used for the first time manganese steel for the rivets with a strength of about 60 per cent in excess of that of ordinary steel rivets.

For suspension bridges in particular the marked improvement in quality of wire steel was of importance. Since the construction of the Brooklyn Bridge in which steel wire of 160,000 pounds per square inch strength was used for the first time in place of the earlier wrought-iron wire, the strength of wire successively stepped up to a new record in almost each new large bridge until it has now reached a strength of nearly 240,000 pounds per square inch in the cables of the George Washington Bridge.

The question is frequently asked, What would be the maximum practical length of span? The answer to this depends essentially upon the quality of steel wire. With the quality now available it would be structurally feasible to build suspension spans of up to about 10,000 feet in length. Such a span, of course, would be extremely costly and probably nowhere justified financially.

SHOP FABRICATION

In the fabrication of structural steel members in the shops important improvements have been made in the past 20 years which were essential for the building of large bridges. Inaccuracies in the fabrication of steel members were largely responsible for the failure of the Quebec Bridge in 1907. Since then more accurate methods and powerful machines have been introduced so that in the present-day large bridges a remarkable degree of accuracy is being obtained. Thus, for instance, the towers of the George Washington Bridge were erected with an accuracy of three-sixteenths inch in a height of 600 feet, and the 1,675-foot arch span of the Bayonne Bridge was closed with a difference of one-half inch from the theoretical length.

To-day individual members of greater size and weight are being completely assembled in the shops. While 30 years ago members of 25 to 30 tons weight were exceptional, the weight attained to-day is not infrequently 80 to 100 tons and in a few cases 150 tons. The accurate fitting together of connecting members is also being given great care to-day. In some cases whole trusses, or large portions thereof, have been completely assembled at the shops.

FIELD ERECTION

When we compare the present day erection of large bridges with that of 20 or 30 years ago, we notice two striking improvements; the speed with which enormous masses of steel for large bridges as well as buildings are being assembled in the field, and the avoidance of cumbersome falsework and erection equipment. The structures often appear during construction as if they were erecting themselves, and this is literally the fact to the extent that frequently members of the final structure proper are being used to lift or temporarily support other members or parts of the structure. Where falsework is unavoidable, it is almost invariably built of steel members which are often members of the permanent structure.

Erection of bridges by the so-called cantilever method with or without partial use of false work, is very common to-day, not only for cantilever bridges, but for simple and continuous trusses and for arches. The absence of false work of any kind is particularly striking in the erection of the towers of suspension bridges. A simple frame carrying the erection derricks and lifting itself up along the completed portion of the tower is the only temporary structure.

The erection of the wire cables in America is accomplished by the old and well-tried method of "aerial spinning," in which the individual wires are pulled from one anchorage to the other over the towers. Then, packed in bundles or strands, the wires are lifted

from temporary into final position in the cable and finally the cable is compacted into cylindrical form and wrapped with a layer of finer wire (pl. 3, fig. 1). While the principle of this method is an old one, having been used already 50 years ago in the Brooklyn Bridge, the machinery and equipment necessary for the spinning have undergone radical improvements which have resulted in greater accuracy and speed of erection.

THEORY AND RESEARCH

Advances in theory and extensive research work have aided materially the construction of large bridges, in fact, refinements in theory and experiments are called for and justified mainly in connection with structures of unusual size. The refinements in theory include the elaborate calculation of secondary stresses of all kinds, stresses which are usually neglected in ordinary structures, but whose magnitude it is well to determine, and where necessary provide for, in larger ones. Such elaborate calculations were carried out in connection with the Hell Gate Bridge, the George Washington Bridge, and more extensively in the Bayonne Bridge.

Stress determinations by calculation are now being supplemented by stress measurements on models. In order to check the highly statically indeterminate stresses in the towers of the George Washington Bridge a celluloid model 6 feet high of one of the tower bents was constructed and the stresses were measured by means of very sensitive extensometers. For the Bayonne Bridge a complete model of the main arch was built of brass, loaded in various manners vertically as well as horizontally and the stresses measured by extensometer. A complete model of the Mount Hope Suspension Bridge was recently built by Professor Beggs of Princeton and the stresses in it measured with excellent results.

As a further means to check the theory, stress measurements by extensometers on the actual structure have been undertaken. Such measurements are now in progress in certain parts of the George Washington Bridge and more extensively in the Bayonne Bridge.

Finally, in order to gain further knowledge of the actual behavior of large-sized members and connections when loaded to destruction, a series of such strength tests have been undertaken. In connection with the George Washington and Bayonne Bridges, for instance, compression tests were made of a number of columns of various materials and of the largest sizes ever tested, taxing the 10,000,000-pound testing machine of the Bureau of Standards in Washington to its capacity. Many tests of large-size riveted connections have also been made in recent years.

ESTHETICS

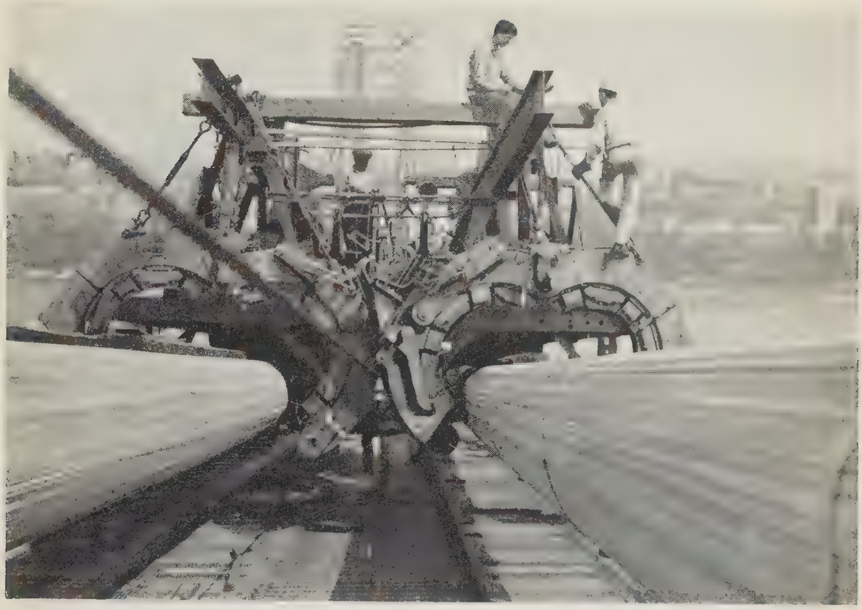
Besides the technical advance in bridge construction we may record welcome developments with respect to the esthetic side. While engineers generally are possessed of a strong sense of utility and are inclined to justify the appearance of any structure from the economic and scientific point of view, there is a marked recognition of the demand of public opinion that proper esthetic treatment be given to our public structures, and that the collaboration of the architect who is trained and better qualified to develop esthetic forms and architectural embellishments is essential for that purpose.

In large bridges, of course, the principal lines and proportions of the structure must be determined by the engineer, for they are, to a large extent, dictated by the fundamentals of strength and stability and by local geographical and topographical conditions. Within certain limits, however, the engineer must and can apply his own sense of beauty in determining them. But it is often essential, in order to improve the general appearance of a structure, to mask or supplement certain crude engineering features by architectural embellishments, the design of which must be left to the architect. It is by such collaboration between engineer and architect that some of our modern large bridges have progressed beyond the field of purely utilitarian and scientific structures.

THE BAYONNE BRIDGE ACROSS THE KILL VAN KULL

Fairchild Aerial Surveys (Inc.)

THE BAYONNE BRIDGE ACROSS THE KILL VAN KULL

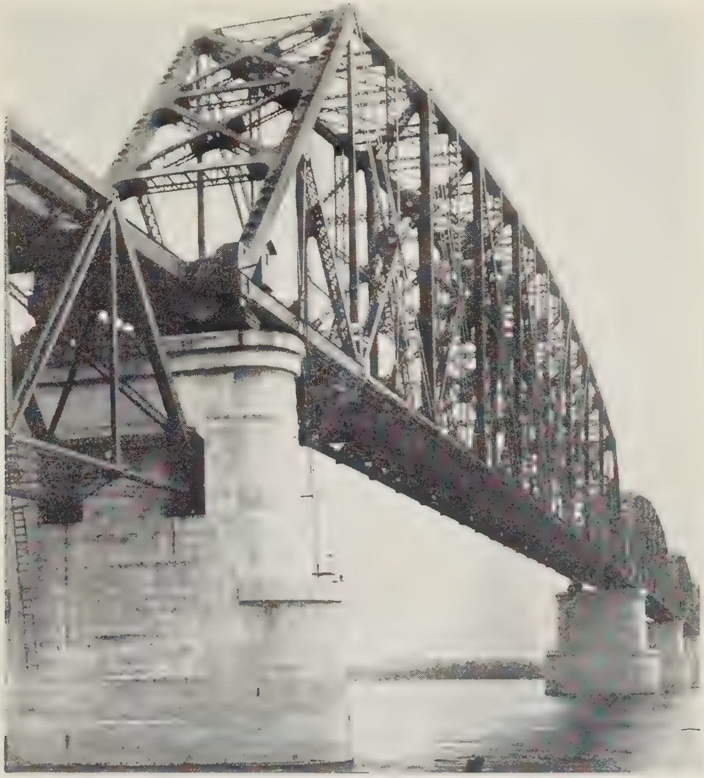


1. COMPACTING THE WIRE CABLES OF THE GEORGE WASHINGTON BRIDGE

2. CANTILEVER ERECTION OF HELL GATE ARCH BY TEMPORARY BACKSTAYS

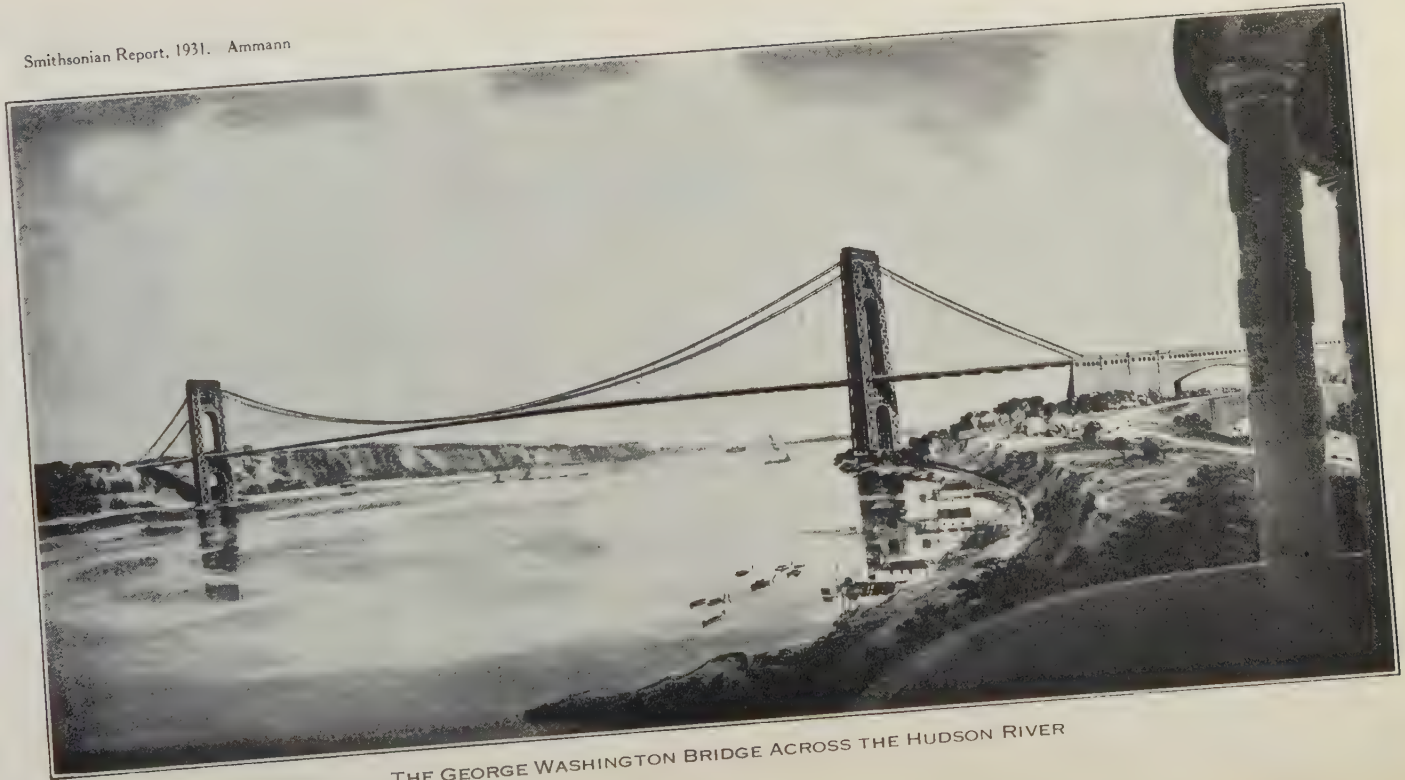
1. SCIOTOVILLE BRIDGE OVER THE OHIO RIVER. LONG SPAN CONTINUOUS TRUSS (2 SPANS OF 775 FEET)

2. BUILDING THE CONCRETE ARCHES OF THE WESTINGHOUSE MEMORIAL BRIDGE, PITTSBURGH

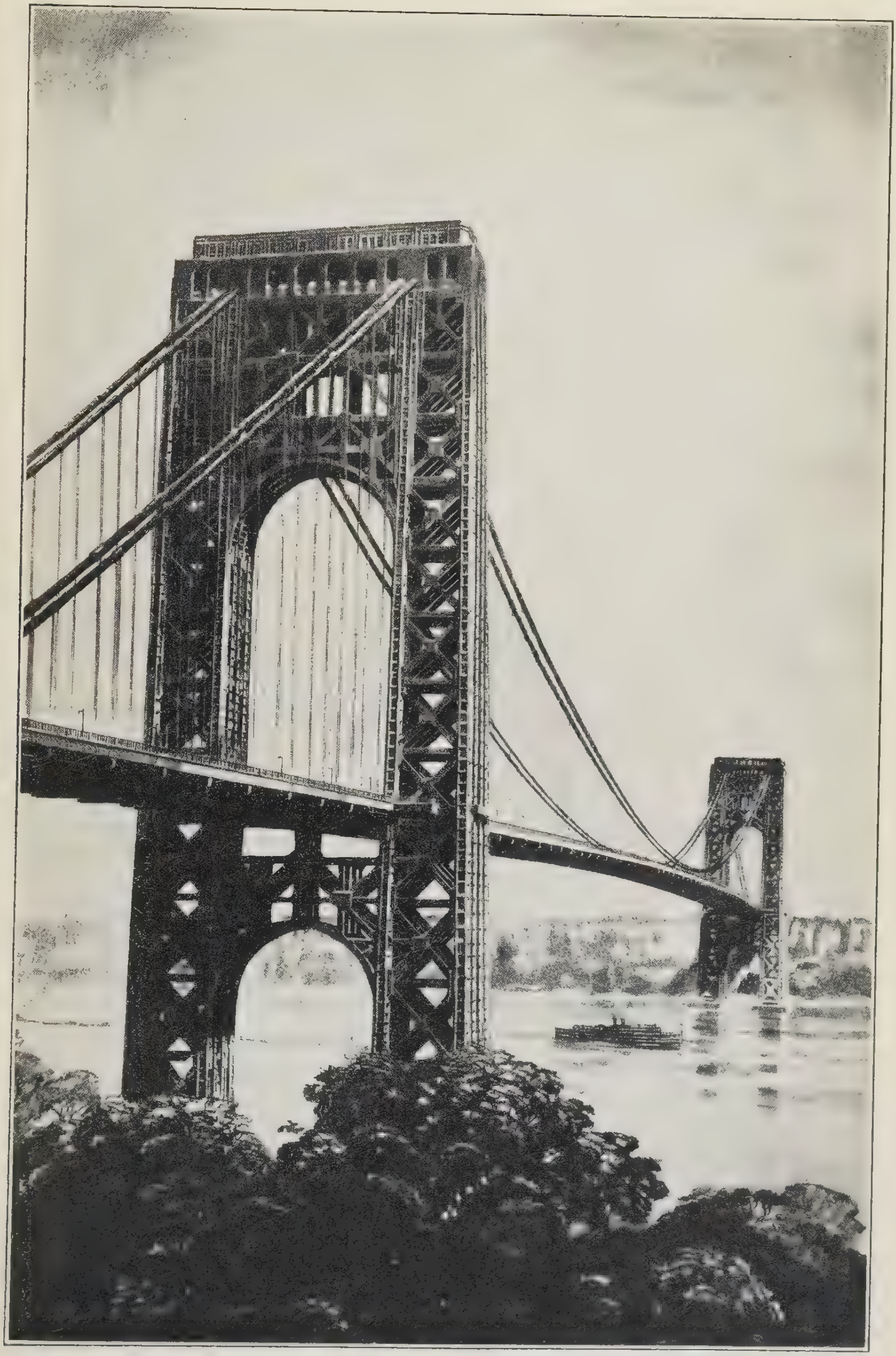


1. 720-FOOT SIMPLE SPAN OF THE METROPOLIS BRIDGE OVER THE OHIO

2. METHOD OF ERECTING CANTILEVER BRIDGE, OUTERBRIDGE CROSSING AT NEW YORK



THE GEORGE WASHINGTON BRIDGE ACROSS THE HUDSON RIVER



THE GEORGE WASHINGTON BRIDGE ACROSS THE HUDSON RIVER SHOWING THE DETAILS OF ONE OF THE TOWERS

ALBERT ABRAHAM MICHELSON 1852–1931

ALBERT ABRAHAM MICHELSON [1]

By Forest R. Moulton

[With one plate]

On May 9, 1931, in his seventy-ninth year and at the zenith of his fame, Albert Abraham Michelson died. As the news of his death was spread by telegraph and cable, the whole world acclaimed his incomprehensible genius; but his intimate acquaintances mourned and still mourn the loss of a friend who was gentle and wholly without affectation.

No scientist of the present day has had a more romantic life than that of Michelson. As a small child, his parents brought him to the United States from Strelno, Germany, where he was born on December 19, 1852. His school days were spent in San Francisco, Calif. In 1869, at the age of 17 years, he made a journey alone across the continent to Washington in order to apply personally to President Grant for an appointment as a cadet in the United States Naval Academy at Annapolis, Md. Since genius has a habit of recognizing its kind, he received the appointment. He graduated in 1873 and became a midshipman in the United States Navy. From 1875 to 1879, inclusive, he was an instructor in physics and chemistry in the Naval Academy; in 1880 he served on the staff of the Nautical Almanac, in Washington; from 1881 to 1883 he studied in Berlin, Heidelberg, and Paris; he was professor of physics in Case School of Applied Science, in Cleveland, Ohio, from 1883 to 1889; from 1889 to 1892 he was a professor in Clark University, in Worcester, Mass.; and in 1892 he answered President W. R. Harper's call to join the new adventures in research, scholarship, and education which were then being started on the Midway, in Chicago. Until his retirement in 1927, he was head of the department of physics in the University of Chicago and he was the first distinguished service professor in the university.

Many of the great scientific societies of the world elected Michelson to their membership. Moreover, he received numerous prizes and medals, among which were the Copley medal of the Royal Society

[1] Reprinted by permission from Popular Astronomy, vol, 29, No. 6, June–July, 1931.

and the Nobel prize for physics, in 1927, in each case the first granted to an American. Many universities, both American and foreign, honored themselves by bestowing upon him honorary degrees. He was president of the American Physical Society, in 1901–3; of the American Association for the Advancement of Science, in 1910–11; and of the National Academy of Sciences, in 1923–1927.

Dates and lists of honors do not really constitute biography; at the most they form a framework on which may be hung a more or less adequate picture of an individual. No intimate friend of Michelson ever thought of him in terms of high positions or great honors. To me he was like the sea on a summer's day—serene, illimitable, unfathomable. This was not a superficial impression, for I knew him intimately for more than 25 years. On scores of occasions I played tennis with him and against him; on a larger number of occasions I played billiards with him. I accompanied him to tennis championships, to billiard matches, and once we occupied ring side seats at a professional wrestling match. Often we took lunch together; many times I called on him in his simple office in Ryerson Laboratory.

I said that to me Michelson was like a serene sea. He was unhurried and unfretful. He was never rushed by university duties; he never drove himself to complete a laborious task; he never feared that science, the university, or mankind was at a critical turning point; he never trembled on the brink of a great discovery. He gave the impression of the serenity of illimitable breadth and unfathomable depth. Though one had a feeling that the depths on occasion might be disturbed by a storm, I never heard him raise his voice above its accustomed level.

There are doubtless many motives that inspire men to scientific achievements. If I have correctly caught the dominant note of his life, Michelson was moved only by the esthetic enjoyment his work gave him. In everything he did, whether it was work or play, he was an artist. His coordination was so perfect and his touch was so deft that there was more satisfaction in being defeated by him at billiards than in winning from another opponent. I recall with what pleasure Professor Sargent, of the art department, used to watch the gracefulness of his playing. Michelson was an artist also in the more ordinary sense of the word, for he was a skillful amateur performer on the violin and his water colors were a delight. And often at luncheon on the back of a menu card he would sketch the profile of a colleague. But all these expressions of his artistic nature were in private and purely for his own pleasure, and many of his friends were quite unaware that he had these accomplishments.

Michelson's art was also manifested in his experiments, even in the first experiment he performed, that of measuring the velocity of light as a class demonstration, at Annapolis. With his hastily con-

structed apparatus he secured results of a higher order of accuracy than any that had theretofore been attained. Much of his scientific work throughout his long life related to light, and his last experiment, completed just before his death, was an extraordinarily accurate measurement of its velocity. In all of his experiments he exhibited an uncanny ability to make apparatus work. For example, after French physicists thought they had proved both theoretically and experimentally that interference phenomena could not be secured in white light, he set up in Paris his recently invented interferometer with the materials that happened to be available and astonished the French scientists with its performance. For the purpose of measuring short distances or small angles, the interferometer is incomparably superior to the microscope. An outgrowth of this early instrument is his later stellar interferometer with which in recent years the diameters of several stars have been measured.

Early in his scientific career Michelson, in association with E. W. Morley, performed an experiment which marks a turning point in the philosophy of physical science. To the mass of mankind the surface of the earth appears fixed, but to the astronomer the earth is a tiny globe which spins on its axis and revolves about the sun. If one should be tempted to conclude that motion with respect to the sun is absolute, astronomers would inform him that the sun moves with respect to the stars; and recently it has been found that our galaxy is moving with respect to exterior galaxies.

In 1887 Michelson and Morley undertook to measure the motion of the earth, not with respect to the sun, or our galaxy, or exterior galaxies, but with respect to the ether, an assumed all-pervading medium through which light is transmitted and which, if anything, would give absolute motion. The quantity to be determined was so minute that it could be measured only with the aid of Michelson's interferometer. To the astonishment of scientists no certain motion of the earth with respect to the assumed ether was found. Though light has the properties of wave motion, it appears to be propagated with a speed which is independent of the motion of its source.

Einstein's theory of relativity has its roots in the Michelson-Morley experiment. All the changes in point of view it has introduced into physics and astronomy rest upon the experiment carried out in Cleveland in 1887, and upon the subsequent verification of its surprising results. Whatever modifications the theory of relativity may undergo and whatever may be its ultimate fate, the results of the Michelson-Morley experiment stand.

In 1913, Michelson and Gale carried out their first earth-tide experiment, the purpose of which was to determine the degree of rigidity and of elasticity of the earth. Sir George Darwin had built

up a beautiful theory of the tidal evolution of the earth-moon system, including the separation of the moon from the earth by fission, on the hypothesis that the earth as a whole is a viscous body. A number of us in 1909 had concluded from dynamical and geophysical considerations that the theory of tidal evolution is quantitatively errroneous. The tide experiment and the associated laborious mathematical work were undertaken cooperatively for the purpose of testing the basic hypothesis of the tidal theory. As scientists generally know, it was found that the earth on the whole is as stiff and as elastic as steel.

The brilliancy of Michelson as an experimenter is well illustrated by the tide experiment. Although the radius of the earth is uncertain by several hundred feet, he measured the variations it undergoes as a consequence of the tidal forces of the moon and the sun to within one-hundredth of an inch. The final series of measurements, extending throughout all of 1917, were automatically recorded on motion picture film by the aid of his interferometer.

Another adaption of the interferometer led to a means of measuring the diameters of minute satellites and planetoids and of the larger of the stars. It is applicable also to measuring the distances between the components of double stars which are so close together as to be completely inseparable by the most powerful telescopes.

Although Michelson's work has had an enormous influence on science and will be referred to as basic for generations to come, he published a relatively small number of papers and books, only about 75 in all. He never rushed into print with immature work. He was not in the habit of publishing the same thing over and over again in slightly varying form. He did not run around the country, posing as a genius and addressing minor scientific organizations. He never invited the press to carefully timed dramatic announcements before the major scientific societies. He never proclaimed the explosion of the universe. He never attracted popular attention and approval by claiming to find support for theological dogmas or the doctrine of the freedom of the will in the laws of falling bodies or in any other scientific principles. Instead, he pursued his modest and serene way along the frontiers of science, entering new pathways and ascending to unattained heights as leisurely and as easily as though he were taking an evening stroll.

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